ISSN 1822-296 X (print)
ISSN 2351-7034 (on-line)

KAUNAS UNIVERSITY OF TECHNOLOGY
KLAIPĖDA UNIVERSITY
JSC LITHUANIAN RAILWAYS (AB “LIETUVOS GELEŽINKELIAI”)
IFToMM NATIONAL COMMITTEE OF LITHUANIA
LITHUANIAN SOCIETY OF AUTOMOTIVE ENGINEERS
THE DIVISION OF TECHNICAL SCIENCES
OF LITHUANIAN ACADEMY OF SCIENCES
VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
PUBLIC ENTERPRISE ROAD AND TRANSPORT RESEARCH INSTITUTE

TRANSPORT MEANS 2018

PROCEEDINGS OF THE 22nd INTERNATIONAL SCIENTIFIC CONFERENCE

PART I

October 03 – 05, 2018
Trakai, Lithuania

KAUNAS • 2018

CONFERENCE IS ORGANIZED BY
Kaunas University of Technology,
In cooperation with
Klaipeda University,
JSC Lithuanian railways (AB “Lietuvos geležinkeliai”),
IFToMM National Committee of Lithuania,
Lithuanian Society of Automotive Engineers,
The Division of Technical Sciences of Lithuanian Academy of Sciences,
Vilnius Gediminas Technical University
Public Enterprise Road And Transport Research Institute

CONFERENCE IS SUPORTED BY
JSC Autofortas Motors

The proceedings of the 22nd International Scientific Conference Transport Means 2018 contain selected papers of 6 topics: Intelligent Transport Systems; Infrastructure, Vehicles/Modes and Flows; Mobility, Safety, Transport Economics; Sustainable Transport Solutions; Defence Technologies; Waterborne Transport.

All published papers are peer reviewed.

The style and language of authors were not corrected. Only minor editorial corrections may have been carried out by the publisher.

Conference Organizing Committee address:
Kaunas University of Technology
Studentų 56
LT – 51424, Kaunas, Lithuania
https://transportmeans.ktu.edu

PREFACE

22nd international scientific conference TRANSPORT MEANS 2018 will be held on 03-05 October, 2018 in „Trasalis – Trakai resort & SPA“, Trakai (Lithuania), Gedimino str. 26. It continues long tradition and reflects the most relevant scientific and practical problems of transport engineering.

The conference aims to provide a platform for discussion, interactions and exchange between researchers, scientists and engineers.

The reports cover a vide variety of topics related to the most pressing issues of today’s transport systems development.

The main areas covered in plenary session and in the sections are: design development, maintenance and exploitation of transport means, implementation of advanced transport technologies, development of defense transport, environmental and social impact, advanced and intelligent transport systems, transport demand management, traffic control, specifics of transport infrastructure, safety and pollution problems, integrated and sustainable transport, modeling and simulation of transport systems and elements.

In the invitations to the conference, sent five months before the conference starts, the instructions how to prepare reports and how to model the manuscripts are provided as well as the deadlines for the reports are indicated.

Those who wish to participate in the conference should send the texts of the reports that meet relevant requirements under indicated deadlines. Each report must include: a short description of the idea or technique being presented, a brief introduction orienting to the importance an uniqueness of the submission, a thorough description of research course and comments on the results.

The submissions are matched to the expertise according to the interests and are forwarded to the selected reviewers.

Scientific Editorial Committee revises, groups the properly prepared reports according to the theme and design the conference programme.

The Proceedings are compendium of selected reports presented at the Conference.

Member of Lithuanian and
Swedish Royal Engineering Academies of Sciences

Prof. V. Ostaševičius

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Electric Energy Harvesting Solutions Review from Roads Pavements

S. Colagrande[1], G. D'Ovidio[1]

[1]*University of L'Aquila, DICEAA, Via G. Gronchi 18, 67100 L'Aquila, Italy E-mail: sandro.colagrande@univaq.it*

Abstract

This paper is concerned with an overview of novel experimental green technologies roadway energy harvesting that could guarantee, in a not so distant future, a significant source of electric power and lead a decrease of greenhouse gases (CO_2) emission.
Two different most promising free emission technologies for energy harvesting from road pavements are considered and analyzed as: the piezoelectric system for generating electric power from vehicular traffic stresses and the photovoltaic panels for converting solar energy into electricity.
Finally, as case study, a preliminary application analysis of these two technologies on an A24 motorway section located in central Italy has been carried out and the results are discussed and compared in terms of energy production.
KEY WORDS: *roads energy harvesting, piezoelectric roadways, solar roadways, renewable energy*

1. Introduction

Even if compared to the past decade vehicles have become more energy efficient, current EU transport still depends on oil and oil products for 96% of its energy needs. EU strategy implies the drastic reduction of world greenhouse gas emissions by 80-95% below 1990 levels by 2050. It is clear that the actual transport system is not sustainable and it cannot develop on the next years along the same criteria [1].

In this scenario, innovation in technology of "zero" emission vehicles [2, 3] and sustainable infrastructures can play a key role for emissions reduction. These considerations point out the necessity of investing in the innovation of transport systems (vehicles, infrastructures and their interactions) considering alternative solutions.

Current highway network is the result of a design and development model conceived in the sixties. This implies that we are actually dealing with the technologies and the road conception developed more than 55 years ago. Nowadays, on the contrary, the highway when properly designed and requalified through the integration of specific systems, it can become a valuable energetic source [4].

It is well known that EU transportation (both commercial and non-commercial) mainly take place by road and has been noticeably increasing year by year. In particular, the middle-long-range transport is mostly practiced on the highway network.

Since the energetic and emission problems have a global impact, it is necessary to explore and test novel technologies for all road infrastructures sustainability [5].

2. Technologies for Electric Energy Production from the Road Pavements

Internationally different technologies are developed and tested in order to generate electrical or thermal energies from the road pavements. It should be noted that these technologies are still under development and the experimental applications are limited to very few cases and they have been provided in often very wide range. Moreover, limited scientific publications are available in technical literature.

In this paper the piezoelectric and photovoltaic technologies for electricity production from road pavement are reviewed and analyzed.

2.1. Piezoelectric Technology

Piezoelectric materials (Barium Titanate, Lead Titanate, Lead Zirconate Titanate, etc. [6] are crystals that have the property to generate current when compressed or vibrated and vice versa they generate a stress when voltage is applied to them.

So the piezoelectric devices, if appropriately integrated into an electromechanical system, can be suitable for road applications in order to convert vehicles motion into electrical power.

The working principle is based on the piezoelectricity effect, for which piezoelectric crystals generate electric voltage from elastic deformations (Fig. 1).

Different products (Innowattech, Cook Chennnault, Virginia Tech, Oregon DOT, Berkeley tech. [7]), to be installed under the asphalt pavement (or inside of the railway sleepers) have been designed in order to generate direct current (DC) from the transit of vehicles/trains [8].

As illustrated in Fig. 2, the DC output of the piezoelectric units electrically connected in series can be:

i) converted by DC-to-AC converter in alternate current (AC) for directly feeding electrical devices or the electrical grid;

ii) accumulated in a storage (i.e. battery) system. The accumulated energy can be used for local power needs or transferred into grid.

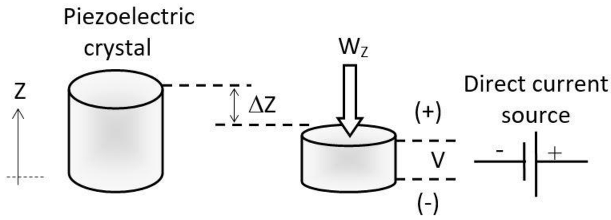


Fig. 1 Work principle of piezoelectric crystal effect

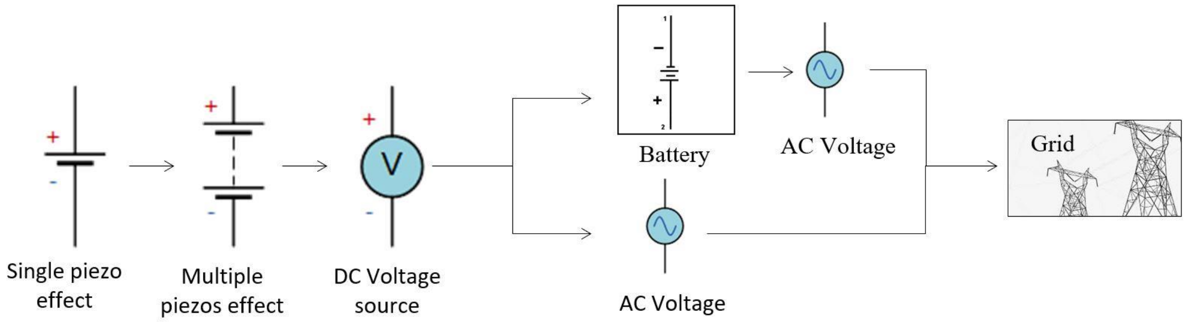


Fig. 2 Flow chart scheme

The main parameters that determine the electricity outcomes of piezoelectricity are: crystalline structure (biomorph or unimorph), geometry (shape) that influence vibration mode, thickness, fixation (fixing constraints between the piezoelectric and the road structure), magnitude of load vertical component (W_Z) [9].

As the piezoelectric device efficiency is strictly related to stress frequency (Hz) and to load (F_Z) magnitude, the road practical system energy power output increases with the rise of vehicles weight and transit frequency (vehicle/h).

The efficiency of piezoelectric devices is also influenced by the type of crystals due to the variety of their properties. However, Lead Zirconate Titanate (PZT) crystals are being used widely to achieve a high piezoelectric effect. The ease of fabrication to any complex shape, high material strength and long-life service, resistant to humidity and heat temperature over 100°C, are all distinctive factors of PZT [10].

An interesting application for the production of piezoelectric energy from roadways comes directly from an Israeli company (Innowatech) with its research offices located in the Institution of Technion, Haifa (Israel). This company has developed a piezoelectric device suitable for producing electricity from the traffic-related movement of the road platform [11].

In particular, the vertical load component (W_Z) by vehicle tires produces a compressive stress that proportionally decreases with depth [12]. For this reason, generators designed by Innowattech are placed in the road pavement to a depth of 5 centimeters, where stresses produced by vehicles are more intense (Fig. 3).

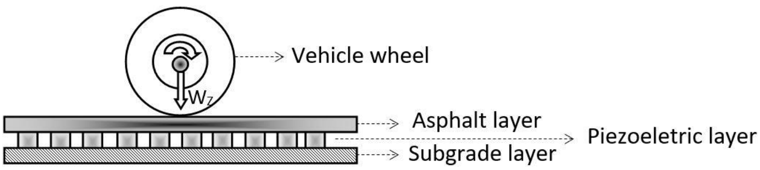


Fig. 3 Piezoelectric roadway cross-section

This solution, when applied to a highway, produces electricity as a function of the number of vehicles, of their weight and speed. Consequently, the greater is the traffic and the more convenient will be this solution.

The operational steps for the piezoelectric generators installation on the road pavement are the following [13]:

- Cutting of the pavement surface;
- Laydown of a quick-setting concrete;
- Positioning of the piezoelectric generators (30 × 30 cm) and drowning in quick-setting concrete;
- Connecting the cables;
- Overlaying the generators with an asphalt layer (to provide better adhesion between concrete and asphalt layer);
- Laydown of final asphalt wearing layer.

Once completed the installation, generators collect the mechanical energy produced by vehicles and convert it into electricity, which is then transferred in storage systems (i.e. batteries) installed along the roadway.

This system provides the following advantages: no occupation of areas adjacent to the roadway, operates in any weather conditions and reduced maintenance operations.

First tests by Innowattech dealt with the installation of piezoelectric nano-generators along a stretch of 10 meters in a road asphalt pavement. In this case the generators could potentially produce about 2 kWh. This trial allowed to experimentally verify that the system works better when traffic is at least 600 vehicles/hour with an average speed of about 72 km/h. Currently the system is under testing and it is characterized by high implementation costs that could be reduced if a production in mass will be promoted [13].

2.2. Photovoltaic Panels as a Road Surface

Nowadays, PV systems are commonly known; they can be distinguished in rooftop or ground-mounted systems and are able to convert solar energy into electricity. Among the multiple uses, there are very interesting photovoltaic panel applications on roadways. In particular, these solar panels can be integrated on noise barriers, shelters of parking service stations or even on the road surface. In this paper we treated about the last type.

The photovoltaic panel placed on the road surface is a pioneering idea by the American engineer Scott Brusaw who, supported by his working team, realized the "Solar Panel Road". This device is a photovoltaic panel able to convert solar energy into electricity and concurrently bear loads and stresses caused by road traffic [14].

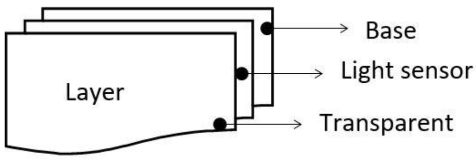
The solar roadway panel, designed to substitute the asphalt wearing course, is composed of the following three layers (Fig. 4, a)

- Surface layer made of a rough glass, anti-abrasive, self-cleaning and highly resistant, which contains photovoltaic cells and led diodes; this layer has the main function to resist weathering and protect the electronic apparatus located underneath;
- Intermediate electronic layer, which contains a microprocessor for controlling and monitoring loadings and lighting;
- Bottom layer, which carries the energy collected by the intermediate layer to various storage systems connected to the roadway and transmit the pavement load to subgrade layer.

Each of the solar roadway hexagonal panels covers an area of about 13.38 m^2 [15]. The DC produced energy is carried to storage systems located near the road surface and can be directed to a primary network for satisfying various energy requirements (e.g. homes, street lighting and road signs, service stations. The DC is converted to AC energy by a DC-to-AC converter or solar micro inverter and then is fed to the electrical grid.

The proceeds would be significant in terms of energy amount: it has been estimated that, for an average daily solar irradiation of 4 hours, each photovoltaic panel should be able to produce around 7.6 kWh per day [16]. However, maintenance procedures for dust accumulation, the duration of photovoltaic cells and the high costs still make the photovoltaic panel for road surfaces in need of improvements.

The Solar Roadways is currently being tested in a section of a highway (70 km long) located between Coeur D'Alene and Sandpoint in Idaho.



a

b

Fig. 4 a - Main layers of panel road; b - Wattway solar panel road [18]

Also in France, a photovoltaic pavement has been realized and named with the explicit term Wattway (Fig. 4, b). This system has been developed by the National Institute of Solar Energy (INES) in cooperation with Colas (company specialized in transport infrastructure). This construction represents an example of a unified concept of photovoltaic road surface: Wattway slabs include photovoltaic cells made of polycrystalline silicon incorporated in a substrate few millimeters thick. At the side, the system is connected to a case that contains electronic security components. The slabs are antiskid, resistant, adaptable to every surface and have been designed to bear the traffic of all types of vehicles, including heavy trucks. The installation of these slabs is very easy: they can be directly glued on the existing pavement surface without any further constructions [17, 18].

3. Case Study

The Italian Motorway A24 (166 km long with 14 sections) that connects on West-East directions the cities of Roma, L'Aquila and Teramo has been selected for carrying out a case study by applying the two road energy harvesting

technology systems described in the previous sections

More in detail, two A24 motorway sections (Fig. 5) have been taken into consideration in order to evaluate the potential electric output of the two different kind of energy harvesting technologies:

- Stretch A: Roma East - Castel Madama toll booths with piezoelectric system;
- Stretch B: L'Aquila East - West toll booths with PV system.

Fig. 5 A24 Motorway

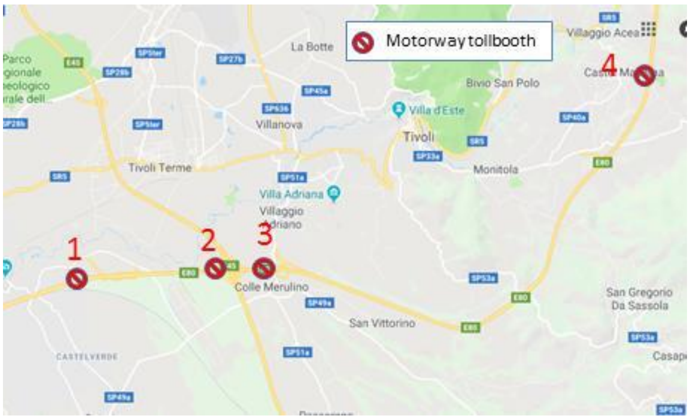


Fig. 6 A24 motorway sections: piezoelectric application

3.1. Piezoelectric System for Road Pavements

A vehicular traffic analysis on all the fourteen A24 motorway sections has been performed by using the data (reference year 2014) provided by the company "Strada dei Parchi SpA" that manage this motorway.

The evaluation of the average annual traffic per hour in each motorway stretches allowed the identification of the segments with more than 600 vehicles/h per direction. Only the first three (near Rome area) out of fourteen segments resulted suitable for the installation in the pavement structure of the piezoelectric device, as follows: segment 1-2 between Roma East toll booths - Connection A1/A24; segment 2-3 between connection A1/A24 – Tivoli toll booths; segment 3-4 between Tivoli– Castel Madama toll booths (Fig. 6).

The system energy output calculation was performed by taking into account the performance data of the Innowattech system [13].

Table 1 lists for each segment the traffic volume and the electric energy per Km. As can be noted, the electric energy production value is between 208 -355 kWh/km for direction. The potential amount of piezoelectric energy that can be potentially produced in this A24 motorway stretch (sections 1-4) is around 7.7 MWh.

Calculation results show an average hourly specific energy output of 0.06457 kW/m^2 equals to about 565 kW/m^2 per year at an average traffic volume of 830 vehicles/h.

Table 1

Energy produced by the piezoelectric device in the A24 Motorway

Segment	Traffic volume, vehicles/h		Energy per Km, kWh		Length, Km	Total Energy, MWh	
	Right lane	Left lane	Right lane	Left lane		Right lane	Left lane
1-2	1066	944	355	315	3.2	1.1	1.0
2-3	881	850	294	283	1.5	0.5	0.4
3-4	630	624	210	208	11.2	2.4	2.3
					Sum	4.0	3.7
					Total	7.7	

3.2. Photovoltaic Panel for Road Pavements

In this sub-section, the installation of PV panel for road pavements in the motorway segment between L'Aquila West and East toll booths was taken into consideration (Fig. 7). The selected motorway section is characterized by an average flow of 220 vehicle/h per lane.

The electric energy (E) produced by a standard photovoltaic (PV) array integrated in a road pavement is calculated as:

$$E = \eta_m \cdot \eta_b \cdot \eta_s \cdot S \cdot G, \quad (1)$$

where η_m is the module efficiency; η_b is the system efficiency taking into account the losses due to temperature and low irradiance (using local ambient temperature), loss due to angular reflectance effects and other losses (cables, inverter etc.); η_s is the losses related to vehicular traffic effect; S is the PV area; G is the average sum of global irradiation per square meter received by the PV modules of the given system.

The PV performance was calculated at L'Aquila location (42°22'0" North, 13°23'22" East, Elevation: 693 m a.s.l.) by using PVGIS-CMSAF tool [19] with the following environmental and technological assumptions:

- Yearly in-plane solar irradiation of 1560 kWh/m^2;
- Cadmiun telluride (CdTe) PV technology;
- Total system losses: $\eta_T = \eta_m \cdot \eta_b \cdot \eta_s = 0.7$.

Fig. 8 illustrates the specific monthly energy output. Calculation results show a specific yearly energy output of 913 kWh/kWpeak which equals to about 130 kWh/m^2 per year.

Fig. 7 L'Aquila West - East toll booths motorway section

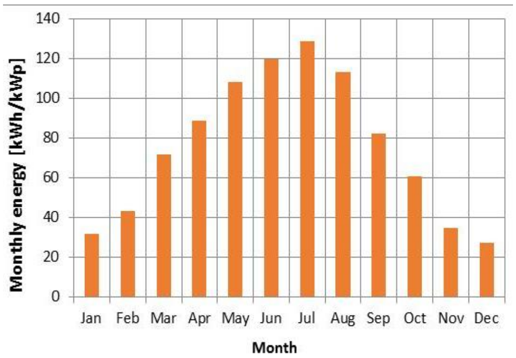


Fig. 8 Monthly energy output

4. Conclusions

In the current paper piezoelectric and PV technologies for energy harvesting from road pavements were reviewed and examined. As case study, the application of the technologies were preliminary simulated on a two different A24 motorway sections in central Italy.

According to the vehicular traffic and environmental conditions taken into account in the study, the results show:

- the piezoelectric system generates an average hourly specific energy output of 0.06457 kW/m^2 equals to about 565 kW/m^2 per year at an average traffic volume of 830 vehicles/h;
- the photovoltaic system generates a specific yearly energy output of 913 kWh/kWp which equals to about 130 kWh/m^2 per year with yearly in-plane solar irradiation of 1560 kWh/m^2.

The results of the preliminary analysis show that the highway when properly designed and requalified through the integration of specific systems, it can become a valuable energetic source.

Future research efforts should seek to better understand the costs of electric energy harvesting solutions from road pavement in order to calculate the energy production cost.

References

1. European Commission 2011. White paper, 144 Final, Brusssels.
2. **D'Ovidio, G.; Masciovecchio, C.; Rotondale A.** 2016. Hydrogen fuel cell and kinetic energy recover system technologies for powering urban bus with zero emission energy cycle, Journal of IET Intelligent Transport Systems 10(9): 573-578.
3. **D'Ovidio, G.; Carpenito, A.; Masciovecchio, C.; Ometto A.** 2017. Preliminary analysis on advanced technologies for hydrogen light-rail train application in sub-urban non electrified routes, Ingegneria Ferroviaria 72(11): 865-878.
4. **Hickson, K.** 2013. Race for Sustainability: Energy, Economy, Environment and Ethics. Singapore.
5. **Xiong, et al.** 2012. New technologies for development of renewable energy in the public right-of-way, DTFH61-10-C-00016. FHWA 9th Quarterly Report, Virginia Tech. October.
6. **Hill, D., Agarwal, A.; Tong, N.** 2014. Assessment of Piezoelectric Materials for Roadway Energy Harvesting. DNV Kema.
7. **Dikshit, T.; Shrivastava, D.; Gorey, A.; Gupta, A.; Parandkar, P.** 2010. Energy harvesting via piezoelectricity, International Journal of Information Technology (2): 265-270.
8. **Kour, R.; Charif, A.** 2016. Piezoelectric roads: energy harvesting method using piezoelectric technology, Innovative Energy & Research 5(1): 1000132.
9. **Ibrahim, S.; Ali, W**. 2012. Power enhancement for piezoelectric energy harvester, Proceedings of the World Congress on Engineering, London 2: 1018-1023.
10. **Nelson, W.** 2010. Piezoelectric materials: structure, properties and applications, New York: Nova Science Publishers.

11. **Edery-Azulay, L.** 2010. Innowattech: Harvesting energy and data; a standalone technology, First International Symposium. The Highway to Innovation, Israel national roads company Ltd, Tel Aviv**.**
12. **Songsukthawan, P.; Jettanasen, C.** 2015. Performance analysis of maximum power transfer in piezoelectric energy harvesting, Proceedings of the International Multi Conference of Engineers and Computer Scientists 2: 670-673.
13. **Kurzweilai, R.** 2011. Innowattech attach harvests mechanical energy from roadways. [online cit.: 2018-04-10]. Available from: http://www.kurzweilai.net/innowattech-harvests-mechanical-energy-from-roadways.
14. **Stephy, J.; Keerthi, S.J.** 2017. A review on solar roadways: the future of roads, International Journal of Recent Innovation in Engineering and Research 2(3): 104-108.
15. **Alark A. Kulkarni** 2013. Solar roadways – Rebuilding our infrastructure and economy, International Journal of Engineering and Applications 3(3): 1429-1436.
16. PhysOrg.com 2009. Solar roadways awarded DOT contract to pave roads with solar cells. [online cit.: 2009-09-07] Available from: https://phys.org/news/2009-09-solar-roadways-awarded-dot-pave.html.
17. Wattway in France 2016. [online cit.: 2016-12-22] Available from: https://www.theverge.com/solar-panel-road-electricity-france-normandy.
18. Wattway by colas 2018. [online cit.: 2018-5-3]: Available from: http://www.wattwaybycolas.com/en/
19. PVGIS-CMSAF tool 2018. [online citation: 2018-06-08] Available from: http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Adaptation and Experimental Analysis of the Universal Asynchronous Receiver-Transmitter Based Communication in Autonomous Ground Vehicle

P. Skačkauskas[1], V. Mejeras[2], V. Žuraulis[3], S. Nagurnas[4]

[1]*Vilnius Gediminas Technical University, J. Basanavičiaus 28, 03224, Vilnius, Lithuania,*
E-mail: paulius.skackauskas@vgtu.lt
[2]*Vilnius Gediminas Technical University, J. Basanavičiaus 28, 03224, Vilnius, Lithuania,*
E-mail: vilius.mejeras@vgtu.lt
[3]*Vilnius Gediminas Technical University, J. Basanavičiaus 28, 03224, Vilnius, Lithuania,*
E-mail: vidas.zuraulis@vgtu.lt
[4]*Vilnius Gediminas Technical University, J. Basanavičiaus 28, 03224, Vilnius, Lithuania,*
E-mail: saulius.nagurnas@vgtu.lt

Abstract

Autonomous ground vehicles (AGVs) are a complex and interdisciplinary research object which combines such areas as vehicle dynamics, automatic control theory, policy framework, etc. Correspondingly, various AGVs control issues, which are combined in the majority of cases, are solved in research works. The control signal formed by the AGVs lateral / longitudinal controller has to be transmitted and executed in real time without any delays or other disturbances. To achieve this goal various serial communication protocols and other communication systems are used. In this work an adaptation of the universal asynchronous receiver-transmitter based communication system (UART) for the use in AGVs is described and analyzed. Proposed adaptation of the UART based communication system was developed in the software package *MATLAB/Simulink*. The analysis was done based on the results of the experimental research using the AGV with the UART based communication system.
KEY WORDS: *autonomous ground vehicle, UART, communication, experimental analysis*

1. Introduction

All transport sector, including industry, logistics, infrastructure, road safety, etc., step by step is getting closer to the point where autonomous ground vehicles will become a common and widely used object. It is assumed that autonomous vehicles will improve the utilizing efficiency of roadways, improve traffic safety, and reduce pollutant emission and energy consumption [6]. However, to achieve these goals faster it is essential to focus on solving such problems as real time motion planning, accurate development of lateral / longitudinal controllers, safe and reliable vehicle-to-vehicle and vehicle-to-infrastructure communication, communication between different autonomous vehicle systems / software, etc. That is why various solutions must be developed and analyzed.

Software has played an increasingly important role in automotive systems over the past two decades and respectively, today’s vehicles have become extremely complex [3]. Under such conditions, development of reliable communication between various controllers for AGV motion and actual vehicle – AGV itself, becomes an even more important task. In general way, AGV / specific part of AGV can be estimated as open or closed loop control system which consists of a controller and a controlled system. Thus, the main aim of the communication system is to ensure that the controlled system would receive the control signal. The most important requirements for the communication system between the controller and AGV itself can be pointed out: the communication system must be able to work in real time with various software without any or with minimal delay, be stable, low-cost and not to corrupt data, data shouldn’t be lost during communication. Even though reliable communication between the controller and AGV itself is an important task, while analyzing AGV as an interdisciplinary object, in most cases, vehicle-to-vehicle and vehicle-to-infrastructure communication problems are considered to be more significant than the communication system between controller and AGV itself problems. In most of the research papers only partial discussion about the communication system between the controller and autonomous vehicle itself can be found. For example, in [8] the communication links with emphasis on Fieldbuses is partially discussed. Fieldbus is described as a communication system which is used in embedded systems and is organized as a layered structure [8]. In [2], for data encoding and decoding a *MAVlink* serial communication protocol is developed. In [3] TDMA-based (time division multiple access) communication protocols were designed to enable real-time communication. For communication in [7], the use of *MOOS App*, which implements such communication protocols as serial port, Ethernet or CAN (controller area network) bus, is noted. In [9] it is indicated that serial link communication has advantages over point-to-point wiring, therefore the authors developed CAN protocol based serial link communication.

Based on the researches described in different sources, it can be seen that, in most of the cases, the developed communication systems are very specific and cannot be used as multipurpose or with various software. Because of this

reason, the aim of this work is to develop and describe the development of communication system, which can be used as multipurpose while seeking to evaluate performance of various AGV controllers or to ensure basic autonomy of vehicle.

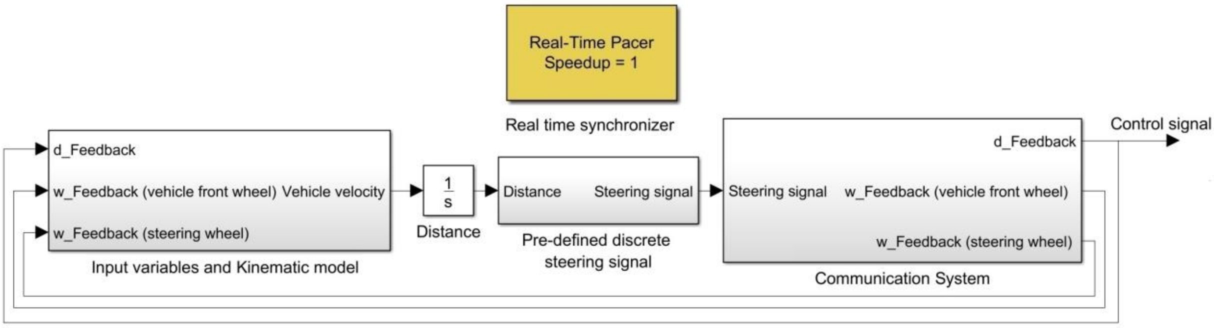
2. Adaptation of UART Based Communication System for AGV

Due to the reason that in a general case any computer can use serial port communication and contains hardware component – universal asynchronous receiver–transmitter (UART) [1], to ensure simple, reliable and effective communication between the controller (computer) and AGV, in this work adaptation of UART based communication system is proposed and described. First of all, for clarity, it must be pointed out that communicating via serial ports requires not only for a controller (computer) to have a serial port, but respectively, for AGV to have a microcontroller which has a serial port, also a cable or wireless interface that provides physical link between the ports and programming to manage the communication must be done [1]. According to [1], programming / managing of the communication consists of two separate key steps: 1. providing and sending data as needed; 2. detecting and processing received data. However, to realize these two tasks in real time, configuration of communication must be performed. During configuration, main parameters, like baud rate, the number of data bits, parity bits, etc., for a serial port that is used for optimal data sending and receiving, are determined. While using UART based communication system with reliable, but non-highest performance microcontrollers like *Arduino* or some of the *STM32* series, etc., due to simplicity maximum value of baud rate, i.e., the rate at which bits are transmitted for the serial interface, during which this type of communication still works reliably, is about 1000000 bits per second [10]. In this work, to adapt UART based communication system for AGV, it is proposed to use baud rate value of 250000 bits per second. Baud rate value of 250000 bits per second is proposed because it was determined that with this value of baud rate an optimal amount of sent data is ensured without distorting the performance of the system. It is important to match baud rate on both communicating devices as the communication in this case is asynchronous. As there is no common clock signal between devices, synchronization is realized through *Start* and *Stop* bits of data packets themselves. As clock frequencies of the communicating devices are higher than bit rates of the transmission, *Start* and *Stop* bits allow a smooth detection of the beginning and end of data packet without losing any bits of information. Regardless, baud rate on both devices has to match within few percent. Otherwise bit value is detected closer and closer to the edge of electrical signal transition until it results in data loss [1]. In order to maintain stable communication without errors, in this work it is also proposed to use common value of 8 bits to transmit over the serial interface, and not to perform parity checking of communication at all, i.e., not to use parity bits. The proposition not to perform parity checking is based on the assumption that AGV will be following pre-defined path in an environment that is not electromagnetically noisy enough to affect data transmission. While using serial port communication, data is transmitted in binary code: each dataset is fragmented in different symbols which correspond to a certain binary sequence. As the microcontroller itself cannot determine the correct order of multiple bytes of data it receives, the order in which two-bytes of a symbol during communication are interpreted, must also be specified. Byte order should be configured based on the used microprocessor: first received byte can be interpreted as least significant one or most significant one.

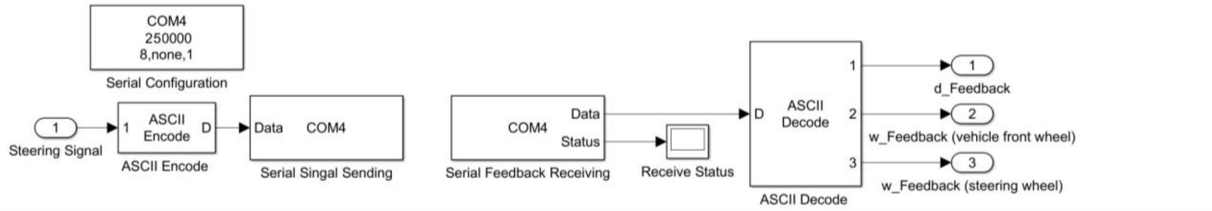
What is important, sending and receiving steps of the communication also should be configured separately. In this case, the sent and received data encoding and decoding should be performed based on the used microprocessor. For example, as described below, in this work communication is formulated between the controller (computer) and autonomous ground vehicles automated steering device with *Arduino* microcontroller. Automated steering device of AGV has a step motor, therefore the actual control signal for the microcontroller is the number of steps of the rotation of the step motor. As in the *Arduino* microcontroller the communication is done using the *ASCII* system symbols, correspondingly encoding and decoding of this type is used (Fig. 1). Furthermore, as already stated, because the sent control signal is the number of steps of the rotation of the step motor, which is an integer number, during encoding and decoding, data type *int16* is chosen. During decoding, from the received *ASCII* system symbols, a number is restored which describes the actual position of steering wheel or front wheels steering angle, etc. Even though the serial ports can exchange just about any type of information, the main disadvantage is that this type of communication cannot always satisfy real time communication condition. Sending or receiving data may need to wait as the operating system attends to other tasks [1]. To ensure optimal performance of UART based communication serial signal sending rate and serial signal receiving rate values must be properly selected.

3. Experimental Procedure

The performance, i.e., the accuracy of path following with different serial signal sending rate and serial signal receiving rate (feedback) values, of the described UART based communication system, were analysed and optimized based on the results of the experimental procedure. In order to perform experimental procedure, kinematic based closed loop controller with the described UART based communication system was developed in the software package *MATLAB / Simulink* (Fig. 1). Respectively, the controller was connected with the *Arduino* software (microcontroller) of autonomous ground vehicles automated steering device while using the described communication system. Due to the reason that the used kinematic controller is based on bicycle-like kinematic model, in this work, the sent and received front wheels steering angle δ signal values are analysed.



a



b

Fig. 1 Controller with the described UART based communication system: a – kinematic based closed loop controller; b – UART based communication system

Experimental procedure was performed while automated steering device of the autonomous ground vehicle was following a rounded rectangle form path coordinates, which was pre-defined using a modified vector based Dubins path approach, the basics of which are described in [5]. The experimental procedure was repeated while changing the serial signal sending rate and serial signal receiving rate values. The used serial signal sending rate values were: 100, 10, 5, 1, 2, 0.5, 0.2 Hz. While changing the serial signal sending rate values, the serial signal receiving rate value was constant – 100 Hz. The used serial signal receiving rate values were: 200, 100, 50, 20, 12.5, 10, 5, 2 Hz. While changing the serial signal receiving rate values, serial signal sending rate value was constant – 10 Hz. During all cases, the step size of mathematical operations solver used in the controller was fixed – 0.01 s.

4. Results and Discussion

The performed experimental procedure is presented in Fig. 2 and Fig. 3, by comparing the results of the front wheels steering angle change and the accuracy of path following, which were obtained while changing the serial signal sending rate and serial signal receiving rate values.

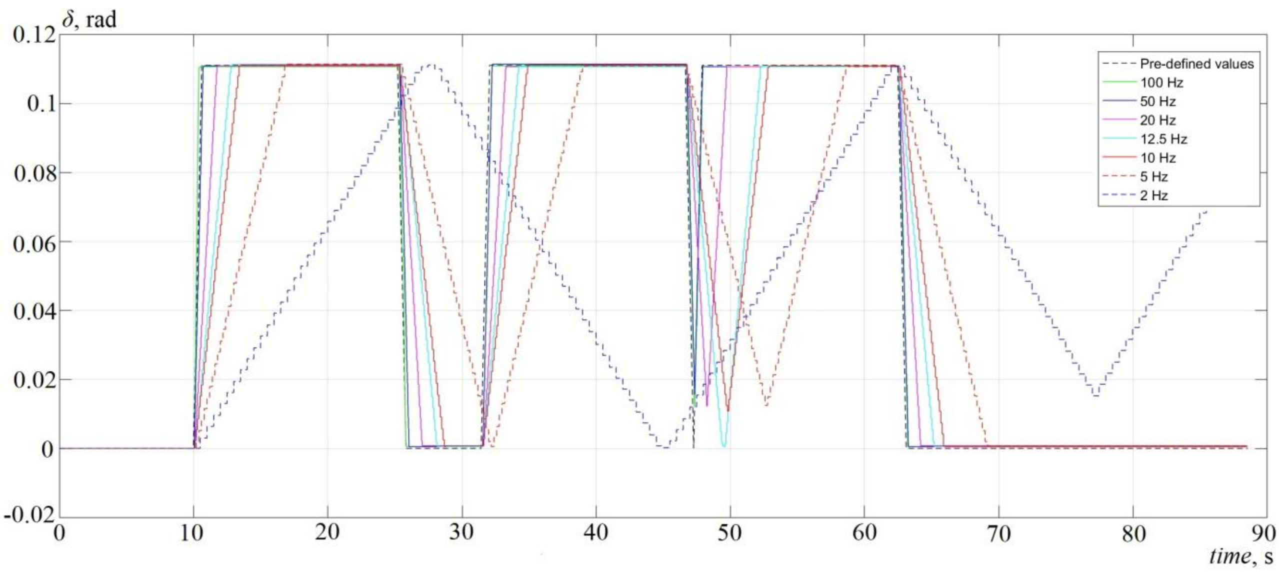
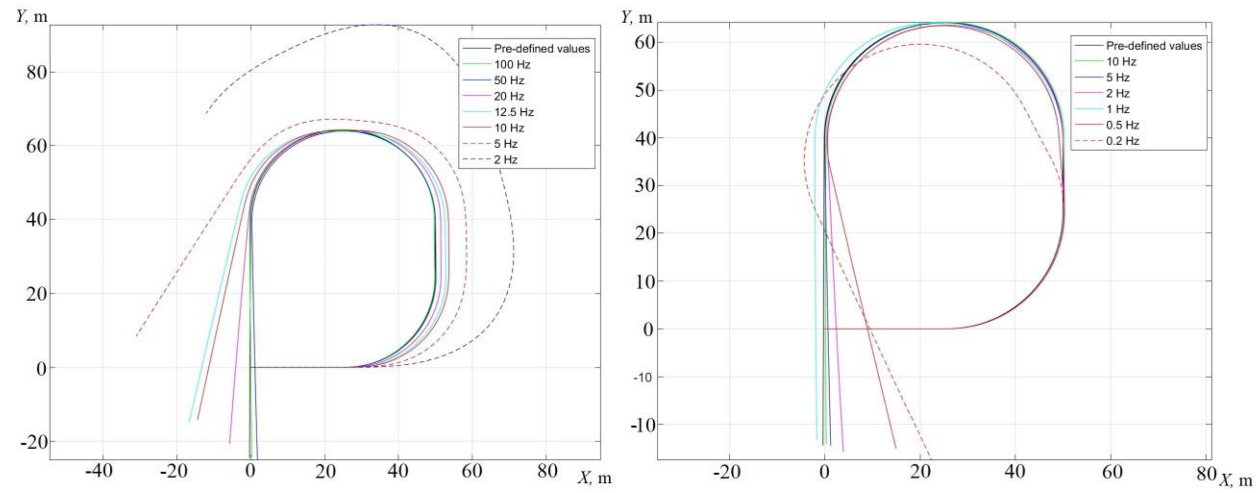


Fig. 2 Feedback data of actual front wheels steering angle values when the serial signal receiving rate values are different



a b

Fig. 3 Movement in pre-defined path: a – actual movement in predefined path when the serial signal receiving rate values are different; b – actual movement in predefined path when the serial signal sending rate values are different

From the feedback data of actual front wheels steering angle values (Fig. 2) it can be seen that when the serial signal receiving rate values, i.e., the frequency of the feedback data receiving, is decreasing, not only the discretization of the signal becomes more coarse and visible but also the time delay until actual front wheels steering angle reaches pre-defined values, grows rapidly. When feedback data receiving frequency is 100 Hz, the average time delay during each change of front wheels steering angle is 0.1 s, respectively: 50 Hz – 0.33 s, 20 Hz – 0.945 s, 12.5 Hz – 1.71 s, 10 Hz – 2.23 s, 5 Hz – 5.02 s, 2 Hz – 16.87 s. These observations can be explained by a few different statements. First of all, when the frequency of the feedback data receiving is decreasing, the data taken from the data buffer is updated with larger time gaps, however, the step size of mathematical operations solver remains constant. This means that the solver used in the controller performs a larger number of mathematical operations with non-updated data and due to this reason the discretization of the feedback signal becomes more coarse and visible. Obvious inaccuracy in the feedback data, because of the coarse signal discretization, can be seen in Fig. 2, around the time point – 50 s. Secondly, during the analysis of the obtained results it was noticed that the described UART based communication system does not ignore or skip any data which is stored in the data buffer. If due to a low feedback data receiving frequency the data buffer is filled with old / non-updated data, the described communication system step by step will send the same data at the size of the fixed step of mathematical operations solver, without skipping it, to the controller, until the more recent / updated values are reached. However, at the time point when the updated data is reached, due to the same reason that the communication system step by step is sending data without skipping it, the reached updated data will also be not the most recent one. This way the time delay in the feedback data is formulated. Seeking to solve this problem and to send the most recent data, in the data buffer the recurring data should be ignored / skipped. Finally, the relation between the feedback data receiving frequency and the delayed reach of pre-defined front wheels steering angle values, can be explained by the fact that the used controller is a closed loop system. When the frequency of the feedback data receiving is decreasing, due to the already mentioned reasons, the controller receives not the most recent and also delayed data. That is why the control signal formulated by the controller is based on the delayed data and respectively, is inaccurate. Based on the results of the experimental procedure it is clear, that when feedback data receiving frequency is decreasing, the inaccuracy of the control signal is increasing, and so is the actual movement inaccuracy in the predefined path (Fig. 3, a). It is also important to notify that when the feedback data receiving frequency is too high (in this work analysed case – 200 Hz), the real time communication condition is not satisfied. This notification can be explained by the already mentioned statement – when the feedback data receiving frequency is too high, the data buffer is emptied faster than the data from the microcontroller is actually received. Because the step size of mathematical operations solver remains constant, the solver used in the controller must perform a larger number of mathematical operations with the repeating latest value used in the data buffer until the data is updated, which takes too much time and the real time communication condition becomes unsatisfied. In the [4] it is also indicated that the need for computer resources, i.e., the duration of the calculation is one of the most important factors that has influence on the speed of variable processing and its decreasing size.

During the analysis of the recorded data, which was obtained while changing the serial signal sending rate values, it was noticed that the decreasing of the data sending frequency does not have the same influence on the actual movement in the predefined path as the feedback data receiving frequency (Fig. 3, b). It can be stated that this is due to the fact that the sent control signal value does not depend on the data sending frequency. However, when the data sending frequency is too low, the actual movement inaccuracy in the predefined path will grow significantly, because, due to the too infrequent updating of the sent signal, the particular time point of the change of the signal can be skipped, therefore a time delay between the controller indicated signal change and the actual moment of the signal change will

appear Similarly to the case of the too high feedback data receiving frequency, if the data sending frequency is too high (in this work analysed case – 100 Hz), the real time communication condition is also not satisfied, because the data sending is performed with too large amounts of the repeating data. Thus, equally, in this case, the solver used in the controller also must perform a large number of mathematical operations with the repeating data, which takes too much time and the real time communication condition becomes unsatisfied. If the step size of mathematical operations solver used in the controller would be smaller, the inaccuracies in the data sending and receiving signals values, also the deviations from the pre-defined path would grow notably. Based on the obtained experimental procedure results and the performed analysis, it can be stated that, when using the described UART based communication system between the kinematic based closed loop controller in *MATLAB / Simulink* software package and the automated steering device with *Arduino* software of the autonomous ground vehicle, the real time communication condition is satisfied and the communication performance is optimal when the serial signal sending rate is 10 Hz and the serial signal receiving rate is 100 Hz (Fig. 2 and Fig. 3).

5. Conclusions

In this work adaptation of universal asynchronous receiver–transmitter (UART) based communication system for autonomous ground vehicle is developed and described. Described UART based communication system is suitable to use while seeking to evaluate the performance of various AGV controllers or to ensure basic autonomy of the vehicle. During the development of the communication systems it was pointed out that the serial signal sending rate and the serial signal receiving rate values are the most important parameters, on which depends a reliable real time performance. It was determined that the real time communication condition is satisfied and the communication performance is reliable when the serial signal sending rate is 10 Hz and the serial signal receiving rate is 100 Hz. If the serial signal receiving rate value is too low, the time delay in the feedback data is formulated, therefore, correspondingly, the control signal of the controller becomes inaccurate and the performance of AGV itself becomes poor. If the serial signal receiving rate value is too high, the real time communication condition is not satisfied. It was also determined that the decreasing of the data sending frequency does not have the same influence on the performance of AGV itself as the feedback data receiving frequency, however, if the data sending frequency is too high, the real time communication condition is also not satisfied. Seeking to clarify the development of the UART based communication system for AGVs, the selection of other parameters, like used data type, baud rate, number of data bits, parity bits, etc., for configuration of communication, data encoding and decoding are described.

References

1. **Axelson, J.** 2007. Serial Port Complete. Madison: Published by Lakeview Research, 400 p.
2. **Coombes, M.; Eaton, W.; McAree, O.; Chen, W.** 2014. Development of a Generic Network Enabled Autonomous Vehicle System, UKACC International Conference on Control, 621-627.
3. **Heinrich, P.; Eilers, D.; Knorr, R.; Koniger, M.; Niehoff, B.** 2011. Autonomous Parameter and Schedule Configuration for TDMA-Based Communication Protocols Such as FlexRay, IEEE 10^{th} International Conference on Trust, Security and Privacy in Computing and Communications: 1241-1246.
4. **Hua, Y.; Jiang, H.; Cai, Y.; Zhang, X.; Ma, S.; Wu, D.** 2017. Path Tracking Control of Automatic Parking Clound Model Considering the Influence of Time Delay, Mathematical Problems in Engineering (2017): 14 p.
5. **Kikutis, R.; Stankūnas, J.; Rudinskas, D.; Masiulionis, T.** 2017. Adaptation of Dubins Paths for UAV Ground Obstacle Avoidance When Using a Low Cost On-Board Sensor. Sensors 17(10): 23 p.
6. **Liu, Y.; Xu, B.** 2015. Improved Protocols and Stability Analysis for Multivehicle Cooperative Autonomous Systems. IEEE Transactions on Intelligent Transportation Systems 16(5): 2700-2710.
7. **Mattos, I.D.; Santos, D.; Nascimento, C.** 2016. Development of a Low-Cost Autonomous Surface Vehicle Using MOOS-IvP. Annual IEEE Systems Conference (SysCon): 6 p.
8. **Nunes, U.; Fonseca, J.A. Almeida, L.; Araujo, R.; Maia R.** 2003. Using Distributed Systems in Real-Time Control of Autonomous Vehicles. Robotica 21: 271-281.
9. **Singh, A.K.; Potluri, R.** 2018. CAN-Based Networked Pat-Tracking Control of a 4WS4WD Electric Vehicle: Maximum Sampling Period, Indian Control Conference (ICC), 369-374.
10. How high of a baud rate can I go (without errors)? [online cit.: 2018-04-30]. Available form: https://arduino.stackexchange.com/questions/296/how-high-of-a-baud-rate-can-i-go-without-errors

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Utilization of the PPP Method for Precise Positioning of the Aircraft in Air Navigation

J. Kozuba[1], K. Krasuski[2]

[1]*Silesian University of Technology, Krasińskiego 13 Street; The Faculty of Transport, Poland, Poland, E-mail: aabuzok@wp.pl*
[2]*Polish Air Force Academy, 35 Dywizjonu 303 Street; The Faculty of Aviation, Poland, E-mail: kk_deblin@wp.pl*

Abstract

The article presents the reliability assessment of determining the Cessna 172 aircraft coordinates during an in-flight test conducted around the EPDE military airport in Dęblin, Poland. Target coordinates of the Cessna 172 aircraft were determined using the PPP precision positioning method for code-phase GPS observations. The coordinates of the Cessna 172 aircraft in the XYZ geocentric system were computed using the IBGE-PPP and CSRS-PPP software. In the article, the of the Cessna 172 aircraft coordinate (x, y, z) difference was determined on the basis of the IBGE-PPP and CSRS-PPP solutions. The mean X coordinate difference value of the Cessna 172 aircraft is -0.18 m, and the RMS error equals 1.24 m. The mean Y coordinate difference value of the Cessna 172 aircraft is 0.91 m, and the RMS error equals 1.25 m. The mean Z coordinate difference value of the Cessna 172 aircraft is -0.21 m, and the RMS error equals 0.46 m. The RMS-3D coordinate precision parameter was also calculated in the article.
KEY WORDS: *GPS, air navigation, GNSS, PPP method, Kalman filter*

1. Introduction

In recent years, GNSS satellite technology has been developing dynamically also in aerospace sector. It should be noted that GNSS satellite receivers have become common instruments onboard aircraft. Moreover, onboard avionics and flight management systems are based mainly on the implementation of the GNSS satellite technology. Ultimately, GNSS single-frequency $L1$, dual-frequency $L1/L2$, or, less frequently, triple-frequency $L1/L2/L5$ satellite receivers are installed on board. It should be emphasized that installation of dual-frequency GNSS receivers onboard an aircraft makes it possible to eliminate, determine, or correct many systematic errors coming from GNSS satellite measurements. Furthermore, such technical infrastructure of an aircraft results in the possibility of utilizing dual-frequency positioning methods. One of such methods of coordinate determination is the Precise Point Positioning (PPP) method. The PPP method is used in static GNSS measurements, but in recent years it has also been used in kinematic mode. On this basis, there is a possibility to use the PPP method both in real-time GNSS measurements and in post-processing [1].

The PPP method is used in air navigation to retrieve the actual aircraft position, as shown below in the examples from the research literature:

- in work [2], the position of the aircraft was determined during an in-flight experiment performed in 2003. The in-flight experiment, the duration of which was 3.75 hours, was performed using an aircraft whose speed was up to 800 kph. The computations were conducted mainly in the P^3 software and in GIPSY/OASIS II for the PPP method. The RMSE position error in the BLh geodesic system between the P^3 and GIPSY/OASIS II solutions is 4.0 cm for B, 5.6 cm for L, and 16.6 cm for h. Furthermore, the standard deviation is 3.8cm, for the B coordinate and for L it is also 4.6 cm, whereas that for the h coordinate it is equal to exactly 9.4 cm. The mean B-coordinate difference between P3 and GIPSY/OASIS II solutions is up to 1.2 cm, for the L coordinate it is 3.1 cm, and 13.7 cm for h.
- in work [3], the position of the aircraft was determined during a flight designated with the number 195, performed in Valencia, Spain, in 2008. The in-flight velocity was approximately 300kph and the flight altitude reached 5300 m. The computations were performed mainly in the magicGNSS, GAPS, and in CSRS-PPP software for the PPP method. The average accuracy of the aircraft coordinates for the GAPS solution in the ENU local system was, respectively: 0.273 m for N, 0.243 m for E, and 0.513 m for U. The average accuracy of the aircraft coordinates for the CSRS-PPP solution in the ENU local system was, respectively: 0.028 m for N, 0.028 m for E, and 0.073 for U. The average accuracy of the aircraft coordinates for the magicGNSS solution in the ENU local system was, respectively: 0.015 m for N, 0.007 m for E, and 0.041 m for U.
- in work [4] the flight trajectory was determined in the ENU local system in two in-flight tests. The computations of the aircraft position were performed mainly in the GrafNav Waypoint program for the PPP method. The values of the aircraft coordinates determined using the PPP method were compared with the results obtained from the differential, DGPS, method. In the first in-flight test, the RMS error for the E coordinate is 2.4 cm, for N it is 2.0 cm, and exactly 3.9 cm for U. In the second in-flight test, the RMS error for the E coordinate is 3.2 cm, for N it is 1.1 cm, and exactly 5.8 cm for U.
- in work [5], the reliability of using the POSPac PP-RTX program in air navigation was determined. The POSPac PP-RTX program was used in over 100 in-flight tests in order to assess the accuracy of the GNSS positioning in air

navigation. The coordinates of the aerial platforms in the NED local system, obtained from all the in-flight tests, were compared with the ASB differential module. The respective RMS error for the E coordinate is 2.1 cm, for N it is 2.0 cm, and exactly 5.6 cm for U. Moreover, the respective standard deviation for the E coordinate is 2.1 cm, for N it is 2.0 cm, and exactly 5.0 cm for U.

- in work [6], the operation of the GrafNav program was verified for the needs of precise aircraft positioning in air navigation. In the work GPS code-phase observations were used from an in-flight test performed in 2003. Typical accuracy of aircraft positioning using the PPP method in BLh geodesic system is approximately 10cm compared to the DD differential solution. Furthermore, the standard deviation is 3 cm, for the B coordinate, and for L it is 6 cm, whereas that for the h coordinate it is equal to exactly 15 cm.
- in work [7], the operation of the CSRS-PPP and GrafNav programs was verified for the needs of precise aircraft positioning in air navigation. In that work, GPS code-phase observations were used, which came from Ashtech and NovAtel OEM3 on-board receivers. Typical aircraft positioning accuracy in the horizontal plane in the local ENU system from the GrafNav program is higher than 6.1cm for all 3 in-flight tests. The accuracy of the vertical coordinate value obtained from the GrafNav program is in turn higher than 6.9 cm for all 3 in-flight tests. Typical aircraft positioning accuracy in the horizontal plane in the local ENU system from the CSRS-PPP program is higher than 9.2cm for all 3 in-flight tests. The accuracy of the vertical coordinate value obtained from the CSRS-PPP program is in turn higher than 12.9 cm for all 3 in-flight tests.
- In work [8], aircraft position during the landing approach was determined using the GAPS program for the PPP method. The position of the aircraft was determined in the geocentric XYZ system based on GPS code-phase observations. Typical positioning accuracy from using the GAPS program is for the X coordinate 4.1 cm, for Y 3.6 cm, and exactly 4.8 cm for Z. Moreover, the MRSE position error for the aircraft ranges from 7.1 cm to 8.0 cm The work compares the coordinate values obtained from the GAPS program with the numerical applications, CSRS-PPP and magicPPP.

In the article, the reliability of XYZ geocentric coordinate determination was made for a Cessna 172 aircraft. The coordinates of the Cessna 172 aircraft were determined using the IBGE-PPP and CSRS-PPP programs for the PPP method. In the computations, $L1$ C/A code GPS measurements were used, which were obtained from a dual frequency Topcon HiperPro receiver installed onboard the Cessna 172 aircraft. The test flight was performed in 2010 around the EPDE military airport in Dęblin, Poland. In the paper, the accuracy of determining the coordinates of the Cessna aircraft was assessed based on the solutions obtained from the IBGE-PPP and the CSRS-PPP programs.

2. Mathematical Model of Precise Point Positioning Method for GPS Observations

The fundamental observation equation for the PPP method is based on the use of the "Ionosphere-Free" linear combination for non-differential GNSS code-phase observations, as written below [9]:

$$\begin{cases} P_3 = \alpha_1 P1 + \alpha_2 P2 = d + c\cdot(dtr - dts) + T + Rel + M_{P3} \\ L_3 = \alpha_1 L1 + \alpha_2 L2 = d + c\cdot(dtr - dts) + T + Rel + B_3 + \delta_{wu} + M_{L3} \end{cases}, \tag{1}$$

where P_3 - the "Ionosphere-Free" linear combination for GPS code observations; L_3 - the "Ionosphere-Free" linear combination for GPS phase observations; (α_1, α_2)- linear coefficients; d - geometric distance between satellite antenna and receiver antenna, contains information about: Earth rotation parameters, solid earth tides, ocean loading, atmosphere pressure loading, movement of continental plate, scale and origin of reference frame, satellite/receiver phase center offset, precise coordinates of satellite and receiver antenna; $d = \sqrt{(x - X_{GPS})^2 + (y - Y_{GPS})^2 + (z - Z_{GPS})^2}$; (x, y, z) - aircraft position in the ECEF geocentric frame; $(X_{GPS}, Y_{GPS}, Z_{GPS})$ - GPS satellites coordinates; c - speed of light; dtr - receiver clock bias correction; dts - satellite clock bias correction; $Trop$ - tropospheric delay; $Trop = SHD + SWD = MF_H \cdot ZHD + MF_w \cdot ZWD$; SHD - Slant Hydrostatic Delay; SWD - Slant Wet Delay; MF_H - mapping function of the troposphere delay for the hydrostatic part in the zenith direction; MF_W - mapping function of the troposphere delay for the wet part in the zenith direction; ZHD - Zenith Hydrostatic Delay; ZWD - Zenith Wet Delay; $\mathrm{Re}l$ - relativistic effect; B_3 - real number of ambiguity; δ_{wu} - phase wind up; M_{P3} - multipath effect for GPS code observations; M_{L3} - multipath effect for GPS phase observations.

The unknown parameters in Eq. (1) are estimated using Kalman filter method in 2-step processing as below [10]:

a) update step:

$$\begin{cases} x_p = A_0 \cdot x_0 \\ P_p = A_0 \cdot P_0 \cdot A_0^T + Q_o \end{cases}, \tag{2}$$

where A_0 - matrix of coefficients; x_0 - a priori value of estimated parameters from previous step; P_0 - a priori value of covariance matrix from previous step; x_p - predicted value of estimated parameters; P_p - predicted value of covariance matrix; Q_0 - a priori covariance matrix of process noise;

b) correction step:

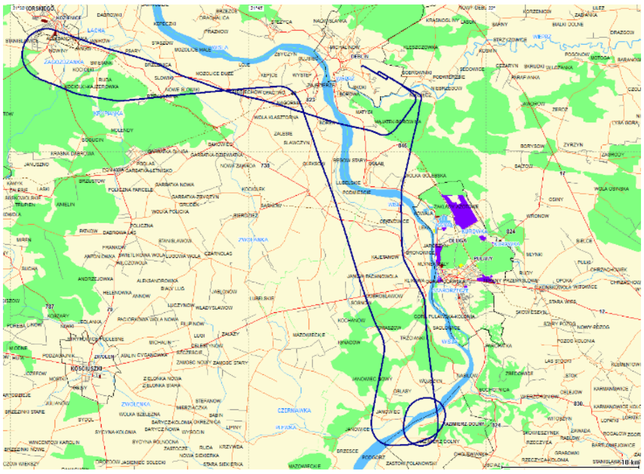
$$\begin{cases} K_k = P_p \cdot H^T \cdot \left(H \cdot P_p \cdot H^T + R \right)^{-1} \\ x_k = x_p + K_k \cdot \left(z - H \cdot x_p \right) \\ P_k = \left(I - K_k \cdot H \right) \cdot P_p \end{cases}, \tag{3}$$

where R - covariance matrix of measurements; H - full matrix; K_k - gain Kalman matrix; z - vector of measurements; I - identity matrix; x_k - a posteriori value of estimated parameters; P_k - a posteriori value of covariance matrix.

The so-determined coordinates of the aircraft (x, y, z) are referred to the ortho-Cartesian XYZ geocentric coordinate system. Moreover, the covariance matrix of the aircraft coordinates determined is also referred to the geocentric ECEF system. In the stochastic process, the receiver clock correction dtr and the wet part of the tropospheric delay, ZWD (zenith wet delay), are also determined. Parameterization of aircraft coordinate changes for each measurement epoch is implemented using the white noise model.

3. Research Experiment

Within the scope of the work presented, a research test was carried out regarding the implementation of the PPP method for precise aircraft positioning in air navigation. The authors' main task was to retrieve the real coordinates of the Cessna 172 aircraft in the XYZ geocentric system. In the research test, GPS code-phase observations were used to retrieve the position of the Cessna 172 aircraft. GPS non-differential observations were recorded by the Topcon HiperPro geodesic receiver placed in the cockpit of the Cessna 172. A trial test flight of the Cessna 172 aircraft was conducted in June 2010 in the vicinity of the military airport in Dęblin, Poland, (see Fig. 1). The route of the Cessna 172 aircraft around the airport in Dęblin was based on the following towns: Dęblin – Kozienice – Kazimierz Dolny – Puławy – Dęblin. The primary objective of the Cessna 172 flight was to obtain research material for accuracy analyses of the air traffic monitoring system being built at that time. In addition, the test flight with the Cessna 172 aircraft mentioned above was carried out within the scope of the research project: "Monitoring System for Aircraft and Vehicles of Public Order Services Based on GNSS". Within the scope of the in-flight test, the achievement of satellite positioning parameters in air transport was also monitored, i.e. the values of accuracy, reliability, continuity, and availability of the GNSS signal. Test flights were also conducted in other cities in south-eastern Poland, e.g. at the airports in Mielec and Chełm. It should be stressed that the monitoring of the quality parameters of GNSS satellite positioning in air transport mentioned above contributes significantly to the safety of air operations.



Source: Author's own work, developed on the basis of IBGE-PPP and CSRS-PPP software

Fig. 1 The Cessna 172 flight trajectory in the horizontal plane

For the purposes of the article, aircraft coordinates were determined on the basis of the GPS solution obtained from the IBGE-PPP and CSRS-PPP programs. Free calculation services, IBGE-PPP and CSRS-PPP, were used in the calculations. For the purposes of the research conducted, the configuration of the parameters being determined, and of models used in the calculations in both programs is presented below:

- GNSS system: GPS system in IBGE-PPP and CSRS-PPP software;
- GNSS system time: GPS time in IBGE-PPP and CSRS-PPP software;
- observation type: code P1/P2 observations and L1/L2 phase observations in IBGE-PPP and CSRS-PPP software;
- computation type: post processing in IBGE-PPP and CSRS-PPP software;

- positioning mode: kinematic in IBGE-PPP and CSRS-PPP software;
- positioning method: PPP method in IBGE-PPP and CSRS-PPP software;
- linear combination of observations: Ionosphere-Free linear combination in IBGE-PPP and CSRS-PPP software;
- GPS observations source: RINEX 2.11 file in IBGE-PPP and CSRS-PPP software;
- method of determining the unknowns parameters: Kalman filter in IBGE-PPP and CSRS-PPP software;
- computation interval: 1s in IBGE-PPP and CSRS-PPP software;
- observation weighting: applied in IBGE-PPP and CSRS-PPP software;
- a priori accuracy of the GPS code measurements: 2 m in CSRS-PPP software, 5 m in IBGE-PPP software;
- a priori accuracy of the GPS phase measurements: 1.5 cm in CSRS-PPP software, 1 cm in IBGE-PPP software;
- elevation mask: 10^0 in IBGE-PPP and CSRS-PPP software;
- detection of malfunctioning GPS satellites: applied in IBGE-PPP and CSRS-PPP software;
- instrumental biases DCB P1-C1 and DCB P2-C2: applied in IBGE-PPP and CSRS-PPP software;
- relativistic effects: applied in IBGE-PPP and CSRS-PPP software;
- Sagnac effect: applied in IBGE-PPP and CSRS-PPP software;
- GPS satellite antenna phase center characteristics: on the basis of the ANTEX format in IBGE-PPP and CSRS-PPP software;
- GPS receiver antenna phase center characteristics: on the basis of the ANTEX format in IBGE-PPP and CSRS-PPP software;
- ephemeral data: precise ephemeris SP3 in IBGE-PPP and CSRS-PPP software;
- source of GPS satellite clock data: precise clocks CLK in IBGE-PPP and CSRS-PPP software;
- ionosphere delay: eliminated in Ionosphere-Free linear combination in IBGE-PPP and CSRS-PPP software;
- a priori receiver coordinates: on the basis of RINEX 2.11 observation file in IBGE-PPP and CSRS-PPP software;
- input meteorological data for troposphere model: GPT model in CSRS-PPP software, GPT2 model in IBGE-PPP software;
- troposphere model: GPT model in CSRS-PPP software, GPT2 model in IBGE-PPP software;
- mapping function of tropospheric correction: GMF mapping function in CSRS-PPP model, GPT2 model in IBGE-PPP software;
- receiver clock bias: determined using stochastic model of white noise in IBGE-PPP and CSRS-PPP software;
- output reference frame of coordinates: BLh ellipsoidal frame and also XYZ geocentric frame in IBGE-PPP and CSRS-PPP software;
- stochastic parameterization of aircraft position: aircraft coordinates are determined using stochastic model of white noise in IBGE-PPP and CSRS-PPP software;
- stochastic parameterization of ZWD term: ZWD parameter is determined using stochastic model of random walk in IBGE-PPP and CSRS-PPP software;
- stochastic parameterization of ambiguity term: ambiguity parameter is determined as a constant value in IBGE-PPP and CSRS-PPP software.

4. Results and Discussion

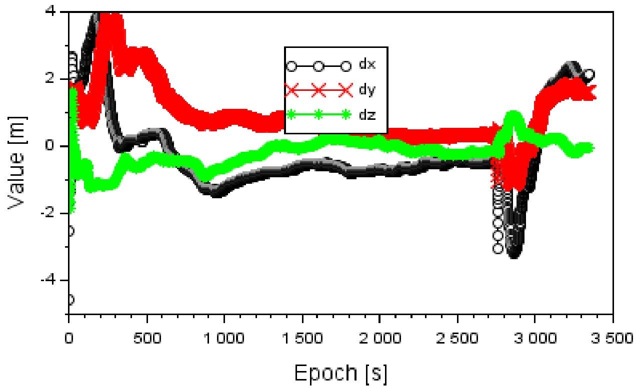
Within the scope of the research, 2 numerical tests were conducted in order to define the reliability of determining the coordinates of the Cessna 172 aircraft for the PPP positioning method. In the first test, the difference of the Cessna 172 geocentric XYZ coordinates was determined on the basis of the IBGE-PPP and CSRS-PPP solutions. The difference in the coordinate values of the Cessna 172 aircraft in the XYZ geocentric system was determined as below [12]:

$$\begin{cases} dx = x_{IBGE-PPP} - x_{CSRS-PPP} \\ dy = y_{IBGE-PPP} - y_{CSRS-PPP} \\ dz = z_{IBGE-PPP} - z_{CSRS-PPP} \end{cases}, \tag{4}$$

where $x_{IBGE-PPP}$ - x coordinate of aircraft from IBGE-PPP solution; $x_{CSRS-PPP}$ - x coordinate of aircraft from CSRS-PPP solution; $y_{IBGE-PPP}$ - y coordinate of aircraft from IBGE-PPP solution; $y_{CSRS-PPP}$ - y coordinate of aircraft from CSRS-PPP solution; $z_{IBGE-PPP}$ - z coordinate of aircraft from IBGE-PPP solution; $z_{CSRS-PPP}$ - z coordinate of aircraft from CSRS-PPP solution.

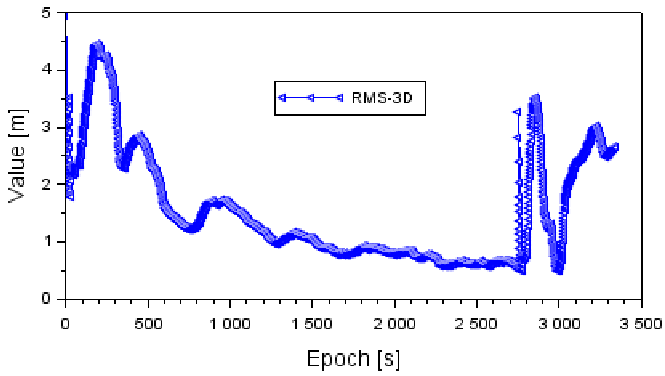
Fig. 2 presents the differences of the Cessna 172 geocentric XYZ coordinates determined on the basis of the IBGE-PPP and CSRS-PPP solutions. The mean difference of the *dx* parameter is -0.18 m, with the median being -0.56 m. Moreover, the dispersion of the *dx* parameter ranges from -4.57 m to +3.84 m. It should be emphasized that the RMS precision error for the *dx* parameter is equal to 1.24 m, whereas the standard deviation is 1.22 m. The mean difference of the *dy* parameter is 0.91 m, with the median being 0.71 m. Moreover, the dispersion of the *dy* parameter ranges from -1.16 m to +3.83 m. It should be emphasized that the RMS precision error for the *dy* parameter is equal to 1.25 m, whereas

the standard deviation is 0.87 m. The mean difference of the *dz* parameter is -0.21 m, with the median being -0.16 m. Moreover, the dispersion of the *dz* parameter ranges from -1.89 m to +1.61 m. It should be emphasized that the RMS precision error for the *dz* parameter is equal to 0.46 m, whereas the standard deviation is 0.41 m. It should be stressed that the lowest values of the (*dx*, *dy*, *dz*) parameters are most noticeable in the middle phase of the Cessna flight. On the other hand, the highest values of (*dx*, *dy*, *dz*) parameters are noticeable in the initial flight phase during take-off and departure, and, additionally, in the final flight phase during arrival and landing.



Source: Author's own work, developed on the basis of IBGE-PPP and CSRS-PPP software

Fig. 2 The difference of aircraft coordinates in XYZ geocentric frame.



Source: Author's own work, developed on the basis of IBGE-PPP and CSRS-PPP software

Fig. 3 The results of the RMS-3D parameter

Fig. 3 presents the values of the $RMS-3D$ parameter, which characterizes the precision of the XYZ coordinates for the Cessna 172 aircraft. The $RMS-3D$ parameter for the XYZ geocentric coordinates was determined on the basis of the relationship [13]:

$$RMS-3D = \sqrt{dx^2 + dy^2 + dz^2} \,. \tag{5}$$

On the basis of the research results obtained, the mean value of the $RMS-3D$ parameter is 1.54 m, with the median being 1.17 m Moreover, the dispersion of the $RMS-3D$ parameter ranges from 0.49 m to 4.96 m. It should be stressed that the lowest values of the $RMS-3D$ parameter are most noticeable in the middle phase of the Cessna 172 flight. On the other hand, the highest values of $RMS-3D$ parameter are noticeable in the initial flight phase during take-off and departure, and, additionally, in the final flight phase during arrival and landing.

5. Conclusions

In the research work presented, the coordinates of the Cessna 172 aircraft were verified on the basis of a solution using the PPP kinematic method. The coordinates of the Cessna 172 aircraft were determined using the PPP method on the basis of the GPS code-phase observations. Observation data were recorded by the Topcon HiperPro geodesic receiver mounted in the cockpit of the Cessna 172. The test flight was performed in the afternoon, in the vicinity of the military airport in Dęblin, Poland. The code and phase GPS observations were recorded with a Topcon HiperPro receiver with a 1-second frequency. The coordinates of the Cessna 172 aircraft were retrieved in the IBGE-PPP and CSRS-PPP numerical programs. The article compares the coordinates of the Cessna 172 aircraft for the IBGE-PPP and the CSRS-PPP solutions. The difference of the Cessna 172 aircraft coordinates (*x*, *y*, *z*) between the IBGE-PPP and the CSRS-PPP solutions reaches the maximum level of ±4.6 m. It is worth mentioning that the RMS-3D parameter for the coordinates (*x*, *y*, *z*) of the

Cessna 172 aircraft ranges from 0.49m to 4.96m. The research results presented in the article are of the utmost importance for the implementation of the PPP method as a part of the ABAS support system in air transport. This is particularly significant for the safety of air operations. In the future, the PPP method may be used to verify the actual aircraft coordinates recorded by an on-board GNSS satellite receiver.

Acknowledgements

The authors would like to thank the IBGE-PPP and CSRS-PPP services for numerical computations of aircraft position.

References

1. **Leandro, R.; Santos, M.; Langley, R.** 2011. Analyzing GNSS data in precise point positioning software", GPS Solutions 15(1): 1-13, DOI 10.1007/s10291-010-0173-9.
2. **Gao, Y.; Wojciechowski, A.** 2004. High precision kinematic positioning using single dual-frequency GPS receiver, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 34(XXX): 845-850.
3. **Martín, A.; Anquela, A.; Berné, J.; Sanmartin, M.** 2012. Kinematic GNSS-PPP results from various software packages and raw data configurations, Scientific Research and Essays 7(3): 419-431, DOI: 10.5897/SRE11.1885.
4. **Hartanto, P.** 2016. The Application of Kinematic GNSS Precise Point Positioning (PPP) for Sulawesi Airborne Gravity Survey, Jurnal Ilmiah Geomatika 22(2): 82-91.
5. **Hutton, J.J.; Gopaul, N.; Zhang, X.; Wang, J.; Menon, V.; Rieck, D.; Kipka, A.; Pastor, F.** 2016. Centimeter-Level Robust Gnss-Aided Inertial Post-Processing for Mobile Mapping Without Local Reference Stations, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B3, 2016 XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic, pp. 819-826, DOI: 10.5194/isprsarchives-XLI-B3-819-2016.
6. **Abel-Salam, M.A.** 2005. Precise Point Positioning using un-differenced code and carrier phase observations, PhD thesis, UCGE Reports Number 20229, pp. 94-98, University of Calgary, Alberta.
7. Waypoint Products Group, NovAtel Inc**.** 2006. Airborne Precise Point Positioning (PPP) in GrafNav 7.80 with Comparisons to Canadian Spatial Reference System (CSRS) solutions, pp. 1-8.
8. **Krasuski, K.; Ćwiklak, J.** 2017. Application of GPS sensor for recovery of precise position of aircraft in air transport, 16th International Scientific Conference Engineering for Rural Development, 16: 222-229, DOI: 10.22616/ERDev2017.16.N042, ISSN 1691-5976, 24-26.05.2017 Jelgava, Latvia.
9. **Sanz Subirana, J.; Juan Zornoza, J.M.; Hernandez-Pajares, M.** 2013. GNSS Data Processing, Volume I: Fundamentals and Algorithms, Publisher: ESA Communications, ESTEC, Noordwijk, Netherlands, ISBN 978-92-9221-886-7, pp. 95-138.
10. **Wierzbicki, D.; Krasuski, K.** 2015. Estimation of rotation angles based on GPS data from a UX5 Platform, Measurement Automation Monitoring, 61(11): 516-520.
11. **Ćwiklak, J.; Krasuski, K.; Jafernik, H.** 2017. Designation the velocity of Cessna 172 aircraft based on GPS data in flight test, 23rd International Conference Engineering Mechanics 2017, ISBN 978-80-214-5497-2, ISSN 1805-8248, pp. 262-265, Svratka, Czech Republic, 15 – 18 May 2017.
12. **Krasuski, K.** 2017. Application the GPS code observations in BSSD method for recovery the position of the aircraft, Journal of Automation, Mobile Robotics & Inteligent Systems 11(3): 45-52, DOI: 10.14313/JAMRIS_3-2017/27.
13. **Krasuski, K.; Wierzbicki, D.; Jafernik, H.** 2018. Utilization PPP method in aircraft positioning in post-processing mode, Aircraft Engineering and Aerospace Technology 90(1): 202-209, DOI: 10.1108/AEAT-05-2016-0078.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Calculation of Logistics Costs in Context of Logistics Controlling

T. Kučera

University of Pardubice, Faculty of Transport Engineering, Studentská 95, 532 10, Pardubice, Czech Republic, E-mail: tomas.kucera@upce.cz

Abstract

Controlling can be understood as a control method for increasing the efficiency of the system through continuous and systematic comparison of the facts and the planned state, identifying the relative offsets, evaluation and search for causes, proposing measures to remedy the identified deviations or update plans. Logistics controlling is closely related to logistics costs, which are accompanied by logistics activities. Logistics costs are an important indicator for measuring the effectiveness of the company. The article deals with cross-section of world literature calculation of logistics costs in the context of logistics controlling. Text is focused not only on the calculation of logistics costs but also on logistics plans and budgets, internal accounting system of indicators of logistics and reporting. The article is based on a search of English, Czech, Polish and Slovak monographs on logistics and costing, articles from the Web of Science database and Scopus database related to calculation of logistics costs in the context of logistics controlling and other sources.
KEY WORDS: *cost calculation, logistics costs, logistics controlling, reporting*

1. Introduction

Logistics is seen as a supply chain functioning to meet customer needs [1, 2]. Logistics activities require adequate economic and environmental effectiveness of sustainability requirements [3, 4]. Controlling over the last few decades is very closely related to logistics and, above all, to logistics costs [5]. The historical background of controlling within the business management economy was first mentioned 80 years ago in the USA [6]. Through the efficient management process, logistics costs can be effectively reduced and, on the contrary, efficiency and better allocation of resources can be increased. The purpose of logistics controlling is to reduce costs and increase the competitiveness of businesses [7].

2. Literature Review and Methodology

Reducing costs and increasing reliability within the supply chain are among the most important business goals [7]. Logistics costs are divided into many industries and this causes difficulties in logistics cost accounting and management [8-10]. Many companies around the world misunderstood the importance of logistics costs [11, 12].

Logistics costs represent a significant component of the total cost of the company, but also of the manufacturing enterprise [13-15]. At present time a lot of attention is paid to these costs in Czech companies [16]. The survey conducted in Germany showed a high logistics cost for both types of businesses - 21.4% of total costs for manufacturing companies and 11.3% of total costs for business organizations. As this survey has shown, it must pay adequate attention to these costs [17, 18]. Logistics managers are usually interested in providing high quality services to their customers at minimum cost [19]. One of the key issues of logistics controlling is the measurement and assessment of the efficiency of logistics processes [20]. The high complexity of logistics systems and the rising cost of logistics performance add to the need for target planning, management, control and coordination of sub-sections of logistics [21]. These tasks then fulfil the so-called logistics controlling, which is to perform and ensure [22-24]:

- permanent control of economy by comparing plan to reality in cost and performance;
- making, densifying and providing information for decision making.

The construction of a complex system of costing and a system of logistic indicators as well as outputs can achieve a highly current way of operating logistic phenomena and processes. In addition, an explicit statement of the causal relationship (causes and consequences between cost and performance) is achieved. This implies a precise definition of performance reference variables and their basis for input/output relationships. The specific focus of controlling is decisively influenced by the field of activity, the policy of the company and the derived factors of success. Business-policy decisions include intentions in relation to capacities, services, fixed costs and budgets to be optimized by logistics controlling. The tasks of logistics controllers are related to the formation of logistics information management, co-operation in logistics planning and logistics control [25-27]. Providing speed and accuracy of information in logistics and in supply chain, is one of the main tasks of logistics controlling [28]. Logistics controlling typically uses tools such as logistics plan and budget, logistics cost calculations, in-house accounting and reporting [22, 23, 29].

The article deals with cross-section of world literature calculation of logistics costs in the context of logistics controlling. Text is focused not only on the calculation of logistics costs but also on logistics plans and budgets, internal accounting system of indicators of logistics and reporting. The article is based on a search of English, Czech, Polish and

Slovak monographs on logistics and costing, articles from the Web of Science database and Scopus database related to calculation of logistics costs in the context of logistics controlling and other sources.

The logistics plan defines logistics goals at the level of strategic and tactical management; the operational procedures leading to the fulfillment of the established logistic plan are then processed into budgets. The objective of the budget is to determine the means to achieve the objectives and the economic outcomes to be achieved. Budgeting thus becomes the primary tool for promoting responsibility for the value level of the company's production value. With regard to logistics, the budget fulfills the function of the annual core budget of logistics. In the creation of budgets, input data are used for transport, individual warehouses, material intake, packing, order management, etc. The stock logistics, customs and tax rates can be determined in the logistics budget [30-32].

In logistics, budgets are generally narrowly focused on individual areas, such as purchasing and inventory budgets, consumption budgets for individual materials, fuel, etc. [30, 31, 33].

In literature and practice, these methods of budgeting are generally available: planned methods, standardized methods, one-off methods and budget estimates [30, 31, 34].

According to Sixta [35], businesses generally underestimate the importance of costing logistics costs. Logistics costs are often included in production, supply or sales overhead, in many cases only in overhead costs. In many cases, neither the owners of the companies nor the managers at all levels of control are aware of them [16].

The purpose of calculating logistics cost calculations can be seen in:

- pricing for the logistics area.
- get adequate documentation for product calculations;
- obtain documentation for processing and checking the financial logistics plan;
- obtain evidence for logistics performance and benchmarking.

Table 1

Cost levels within the calculation [author based on 16]

Simple Calculation	Structured Calculation
Direct Material	Direct Material
Direct Wages	Direct Wages
Indirect (Overhead) Costs	Manufacturing Overhead
	Construction Preparation
	Sales and Distribution Costs
	Leadership Costs
	Marketing
	Research

Table 1 shows two approaches to creating calculations. Simple calculation consists of three components: direct material, direct wages and overheads, while structured calculations consist of direct material, direct wages and from manufacturing overhead, construction preparation, sales and distribution costs, leadership costs, costs from marketing and research [16, 36].

From the point of view of the cost structure, at the present time, attention is paid mainly to the minimization of overhead costs, whose development has recently shown an increasing tendency (see Fig. 1) [37].

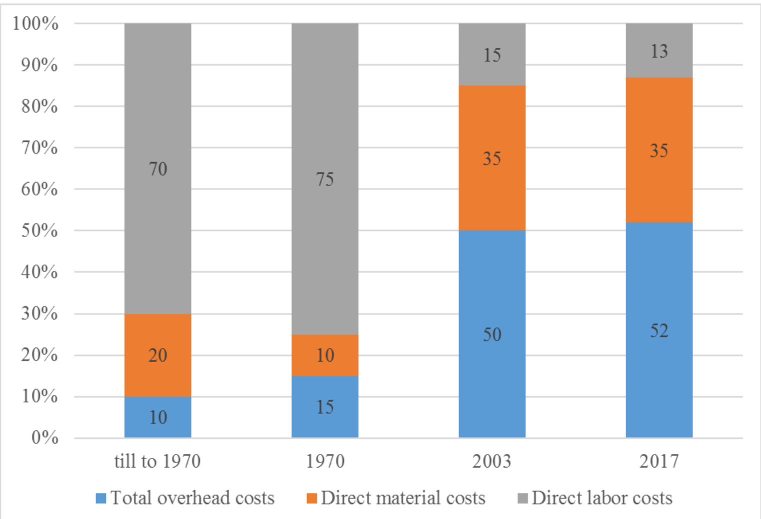


Fig. 1 Development of total costs of the firm [author based on 37]

According to Popesko [38, 39], the calculation, especially in terms of costing, is nowadays regarded as the oldest and today also the most frequently used value management tool. One of the key needs of managers is to identify costs that are associated with the performance of business activities. Therefore, it can be stated that, given the importance of logistics costs in enterprises, the ability to assess the performance of logistics activities is one of the basic prerequisites for successful business [40].

The issue of costing calculations lies primarily in the classification of direct and indirect costs. Above all, the existence of overhead (i.e. indirect) costs and related problems in their allocation gave rise to different calculation methods and allocation principles [39-41].

It should be noted that a properly chosen costing calculation not only refers to the amount of each cost-per-performance group, but also gives an overview of which groups the cost of the performance is structured [41, 42].

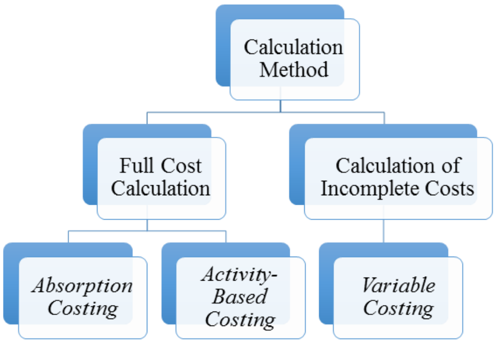


Fig. 2 Basic types of costing calculations [author based on 38, 39, 43, 44]

Fig. 2 illustrates two possible approaches to calculation methods, namely the calculation of full costs and the calculation of incomplete costs. The subject of logistics calculations is the cost of all logistics operations that relate to [38, 39, 43, 44]:

- the unit of measurement, which represents the specific logistic power, the unit of measurement (kg, t, piece, pack, etc.) and the type of performance (warehousing, packaging, transport) to which the costs are related;
- the calculated quantity, expressing a certain number of calculating units related to time (pcs per day, per week, etc.) to the distance or volume;
- the calculation system consists of individual types of costing and calculation methods (division, surcharge, variable and fixed costs).

In order for internal accounting to be an effective tool for logistics management and measurement, it is necessary to modify both synthetic and analytical records so as to allow logistics costs to be monitored, for example, by the types of logistics (synthetic accounts) and corresponding logistics (analytical accounts) [34, 45].

However, in the framework of logistics controlling, the meaning of intercompany accounting is understood in the narrower sense. Through the information obtained from the accounting, it is determined whether the logistics costs were spent at the right time, in the right place and in the required amount, thus controlling answers to the question of why the company achieved profit or loss in the given period [45-47].

According to [48-50] there are three types of performance measures - Key Result Indicators (KRI), Performance Indicators (PI) and Key Performance Indicators (KPI).

KRI - Key Result Indicators tell the user how they acted in their activities. These include, for example, customer satisfaction indicators, net pre-tax profit, and employee satisfaction, return on capital injected. According to [48-50], these are typical information indicators for the board of directors, which is not involved in everyday management. These indicators typically cover a longer period of time than key performance indicators, are reviewed in monthly or quarterly cycles, but not daily or weekly.

PI - Performance Indicators tell the user what to do. KRI and KPI have a number of performance indicators that complement the KPIs and are used in the organization's scorecard. Examples of these indicators are: profitability of major 10% of customers, net profit of non-key production lines, percentage increase in sales of the major 10% of customers, number of employees participating in the improvement program.

KPI - Key Performance Indicators tell you what to do to significantly improve performance. KPIs are a set of benchmarks geared to the organization's performance considerations, which are the most critical for todays and future business success.

Effective use of these indicators in individual business activities such as purchasing, material flow and transportation, warehousing, distribution, production planning and management is conditional on taking into account several basic conditions [48-50]. These are, above all, the usability of the indicators in a particular business, the relationship between utility and the costs generated by the indicator and the ability of the indicators to display the given area. In addition, the indicators should specify the exact purpose of their use in the enterprise and also the responsible persons in the organization who have clear competencies [22, 41, 48-50].

The task of the reports is to provide comprehensive information to the users (managers), in this case logistics costs and performance, logistic indicators monitored, to the required extent, structure and time. Reports are typically

standardized, but the exception is not an exception, both in terms of terms, structure and content [51, 52].

A separate topic related to this issue is also the level of the company information system used, i.e. the data platform, from which the necessary information for the reporting is obtained within the controlling. Today, there is no exception that so-called analytical management modules are available in enterprises, where the most commonly used reports are already preset. These applications are unnecessarily robust or inaccessible for many small businesses. However, this does not mean that business reporting is compromised [33, 51, 53, 54].

One of the best forms of the report are nowadays electronic versions of outputs that contain structured data and can be easily processed and evaluated as needed in the case of a small business for example using a pivot table in MS Excel. Report users are not statically bound and can work with data as needed [53, 55].

3. Research Results and Discussion

The controlling concept is based on the constant comparison of actual logistics costs with planned enterprise costs, the detection of deviations and the causes of these deviations, the monitoring of the effect of deviations on the achievement of a predetermined target that is measurable by economic indicators. Controlling is based on defining the goals the company wants to achieve, i.e. reduce logistics costs. Fig. 3 shows the entire controlling approach.

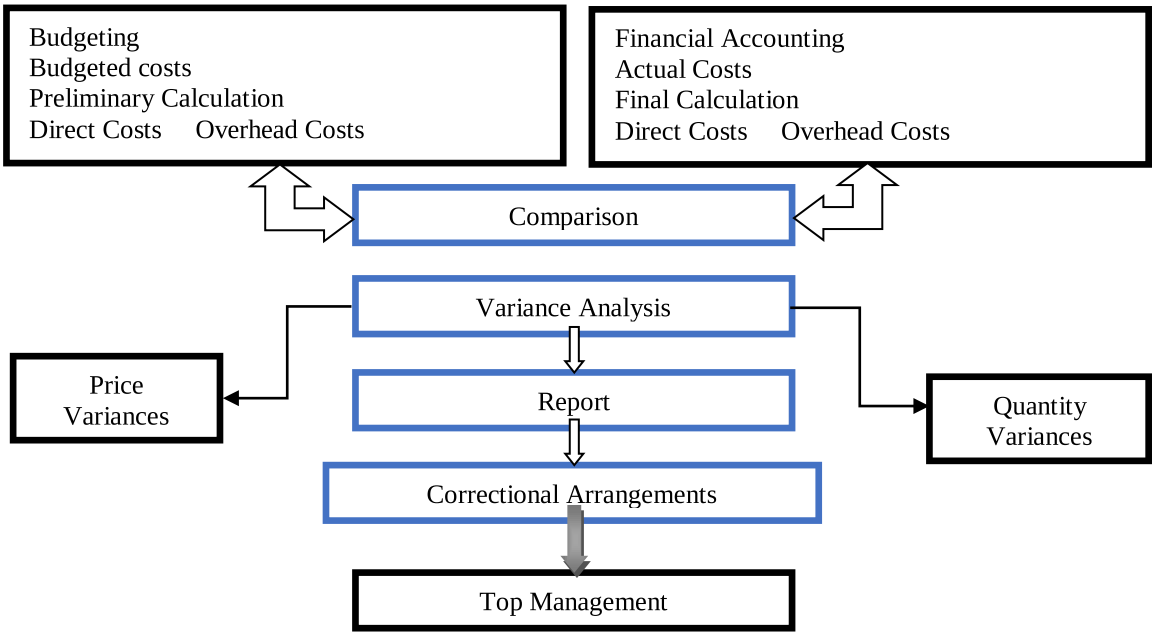


Fig. 3 Controlling approach [author]

The benefit to an enterprise that utilizes a controlling approach in managing logistics costs is to reduce the overheads, which can ultimately affect the price of products, thereby affecting demand and meeting customer requirements, increasing revenue from sales of products, lowering total costs, increasing profits. In addition to financial benefits, it is also necessary to perceive another aspect of this approach, namely to improve the information transmission system at individual management levels, to provide feedback in synergy with the customer, to eliminate inefficient activities in the chain of logistics processes.

4. Conclusions

The application of a controlling management concept presupposes having a highly qualified company management whose aim is to continuously increase the value of the business. The speed of realization of the individual phases of implementation of logistics controlling depends on the revelation, consistency and determination of the top management. In order to ensure the synchronization of the individual logistics processes, the availability of the information needed for the individual management and information levels, the staff assessment, the feedback from the customer and the flexibility in the deviations from the financial plan, it is necessary in today's conditions of high competition that the information flows are of high quality, flowed quickly and in optimal amounts. From this point of view, the place of controlling in the modern society is irreplaceable. Controlling can successfully manage critical business processes and enable the enterprise as a whole to build a concept of continuous improvement in the direction of reducing logistics costs.

Acknowledgment

The work was created in connection with the scientific research project of the University of Pardubice no. SGS_2018_023. The author is grateful for their support.

References

1. **Zhang, L.** 2007. Management of logistic cost based on activity analysis, Commercial Economic 22: 21-28.
2. **Pernica, P.** 2005. Logistika (supply chain management) pro 21. století. Praha: Radix, 524 p. (in Czech).
3. **Witkowski, K.** 2009. The Innovations For Sustainable Development, Proceedings of 17th International Scientific Conference CO-MAT-TECH, Trnava-Bratislava.
4. **Macharis, C.; Melo, S.; Woxenius, J.; Van Lier, T.** 2014. Sustainable Logistics. Bingley: Emerald Group Publishing, 338 p.
5. **Gracyzl, M.; Burchart-Korol, D.; Witkowski K.** 2012. Reverse logistics processes in steel supply chains. Proceedings of 21st International Conference on Metallurgy and Materials, Brno.
6. **Kluge, P.D.; Kuzdowicz, P.; Orzeszko P.** 2005. Controlling wspomagany komputerowo z wykorzystaniem systemu ERP. Zielona Góra: Uniwersytetu Zielonogórskiego, 125 p. (in Polish).
7. **Paulonis, D.; Norton, S.** 2008. McKinsey Global Servey Results: Managing Global Supply Chains. New York: McKinsey&Company.
8. **Rossiter, H.A; Knemeyer, A.M.** 2009. Controlling for logistics complexity: Scale development and validation, The International Journal of Logistics Management 20(2): 187-200.
9. **Wang, H.** 2008. Status and controlling measures of logistics cost in China's logistics industry. International Conference on Wireless Communications, Networking and Mobile Computing, Dalian: IEEE.
10. **Pawellek, G.; Schramm, A.** 2008. Production logistics - controlling of procedures as a steering tool, PPS Management 13(1): 17-21.
11. **Yin, M.** 2007. Analysis and solutions of enterprises logistic cost management, Management World 32: 36-41.
12. **Zhang, Y.** 2007. Measures on Reducing Enterprise Logistic Cost, Logistic Economy 33: 49-59.
13. **Nyhuis, P.; Beck, S.; Schmidt, M.** 2013. Model-based logistic controlling of converging material flows, CIRP Annals - Manufacturing Technology 62(1): 431-434.
14. **Dobroszek, J.** 2014. The use of controlling tools in logistics enterprises in Poland. International conference on accounting, auditing, and taxation, Tallinn: Destech, 133-144.
15. **Dobroszek, J.** 2015. Analysis of factors affecting the implementation of controlling in logistics enterprises and the resulting effects - case of Poland, 20th International Scientific conference – Economics and management, Kaunas: Elsevier Sciences 213: 248-253.
16. **Sixta, J.; Žižka, M.** 2009. Logistika: metody používané pro řešení logistických projektů. Brno: Computer Press, 238 p. (in Czech).
17. **Pernica, P.; Mosolf, H. J.** 2000. Partnership in Logistics, Praha: Radix, 448 p.
18. **Elsweier, M.; Nickel, R.** 2010. Logistic controlling in SME - results of a study and need for action, Productivity Management 15(2): 50-53.
19. **Kučera, T.** 2017. Logistics Cost Calculation of Implementation Warehouse Management System: A Case Study. 18th International Scientific Conference-Logi 2017, MATEC Web of Conferences 134: 1-7.
20. **Saniuk, A.; Saniuk, S.** 2016. The balanced scorecard as a method of the logistics controlling. In: CLC 2015: Carpathian logistics congress – conference proceedings. Jeseník: Carpathian Logistics Congress, 473-478.
21. **Kučera, T.; Hyršlová, J.; Sommerauerová, D.** 2017. Activity-based costing as an innovative management method to logistics cost calculation for warehousing. SGEM 2017, BK 1: Modern science conference proceedings, volume V Business and Management, 25-32.
22. **Schulte, Ch.** 1994. Logistika. Praha: Victoria Publishing, 301 p. (in Czech).
23. **Fibírová, J.** 2003. Reporting: moderní metoda hodnocení výkonnosti uvnitř firmy. Praha: Grada Publishing, 116 p. (in Czech).
24. **Fibírová, J.; Šoljaková, L.; Wagner, J.; Petera, P.** 2015. Manažerské účetnictví – nástroje a metody. Praha: Wolkers Kluwer, 404 p. (in Czech).
25. **Ballou, R. H.** 2003. Business Logistics. Supply Chain Management. Prentice Hall, 676 p.
26. **Ballou, R. H.** 2004. Business Logistics, Supply Chain Management - Planning, Organizing and Controlling the Supply Chain. Pearson Education.
27. **Hofer, A.R.; Knemeyer, A. M.** 2009. Controlling for logistics complexity: scale development and validation, The International Journal of Logistics Management 21(20): 187-200.
28. **Ski, A. K.; Fajfer, P.** 2011. ERP integration as a support for logistics controlling in supply chain, Environmental Science and Engineering (Subseries: Environmental Science), Poznan: Kluwer Academic Publishers, 617-626 p.
29. **Sergeyev, V.** 2016. Logistics controlling as a tool of performance improvement at the Russian enterprises, Transport and Telecommunication Journal 17(2): 100-110.
30. **Vidová, H.** 2009. Logistický controlling, Bratislava: Slovenská technická univerzita, 89 p. (in Slovak)
31. **Čechová, A.** 2006. Manažerské účetnictví, Brno: Computer Press, 182 p. (in Czech).
32. **Machková, H.; Černohlávková, E.; Sato, A.** 2014. Mezinárodní Obchodní Operace, Praha: Grada, 256 p. (in Czech).
33. **Rochow, P.; Hund, E.; Gruss, M.; Nyhuis, P.** 2015. Development of a mathematical model for the calculation of the tool appropriation delay depending on the tool inventory, Logistics Journal 1-11 p.
34. **Zimon, G.** 2016. Accounting tools vs. logistics costs control in a trading company, Logforum 12(2): 155-164.
35. **Sixta, J.** 2004. Využití controllingu v logistice, Ekonomické problémy transformace hospodářství České republiky

s přihlédnutím ke specifikům euroregionu Nisa – Sborník prací výzkumného záměru IV. Díl, Liberec: Hospodářská fakulta TU. 246-268 p. (in Czech).
36. **Bokor, Z.** 2012. Cost calculation model for logistics service providers, Promet - Traffic - Traffico 24(6): 515-524.
37. **Kupkovič, M.** 2004. Náklady podniku, Komplexný pohľad na náklady. Bratislava: Sprint. (in Slovak).
38. **Popesko, B.** 2009. Moderní metody řízení nákladů, Praha: Grada Publishing, 240 p. (in Czech).
39. **Popesko, B.; Papadaki, Š.** 2016. Moderní metody řízení nákladů, Praha: Grada Publishing, 264 p. (in Czech).
40. **Bokor, Z.** 2008. Supporting logistics decisions by using cost and performance management tools, Periodica Polytechnica Transportation Engineering 31(1-2): 33-39.
41. **Škerlič, S.; Muha, R.; Logozar, K.** 2016. A decision-making model for controlling logistics costs, Tehnicki Vjesnik-Technical Gazette 23(1): 145-156.
42. **Škerlič, S.; Muha, R.** 2016. The importance of systems for controlling logistics costs in the supply chain: A case study from the Slovenian automotive industry, Promet-traffic & transportation 28(3): 299-310.
43. **Tesdorpf, W.** 1977. Influence of corporate tax-reform in accounting of domestic intercompany reduced-tax income in annual-report, Düsseldorf: Verlagsgrp Handelsblatt 30(30): 1376-1377.
44. **Rosová, A.** 2010. Indices system design of distribution logistics, transport logistics and materials flow as parts of controlling in enterprise's logistics, Acta Montanistica Slovaca 15: 67-72.
45. **Máče, M.** 2013. Účetnictví a finanční řízení, Praha: Grada, 552 p. (in Czech).
46. **Bertsch, S.; Nyhuis, P.** 2011. Changeable production logistics - A new challenge for the production performance management, ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb 106(9): 630-634.
47. **Qu, Z. M.** 2011. Application of PCA in Controlling and Reducing Enterprise Logistic Cost, Applied Mechanics and Materials 39: 426-430.
48. **Marti, L.; Martin, J.C.; Puertas, R.** 2017. A Dea-Logistics Performance Index, Journal of Applied Economics 20(1): 169-192.
49. **Medina, R.P.; Selva, M.L. M.; Menendez, L.G.** 2014. Logistics Performance Index: European Exports, Revista de Economia Mundial 38: 77-99.
50. **Parmenter, D.** 2008. Klíčové ukazatele výkonnosti, Rozvíjení, implementování a využívání vítězných klíčových ukazatelů výkonnosti (KPI). Praha: Česká společnost pro jakost, 242 p. (in Czech).
51. **Härtel, L.; Schmidt, M.; Nyhuis, P.** 2017. Logistics controlling of company internal supply chains - development of a procedure model for quantitative analysis and evaluation of the root-causes of low logistics performance, ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb 112(4): 238-242.
52. **Lazar, J.** 2012. Manažerské účetnictví a controlling. Praha: Grada, 280 p. (in Czech).
53. **Rochow, P.; Gruss, M.; Nyhuis, P.** 2015. Supply controlling in forging companies - Positioning the tool supply between logistic costs and performance, ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb 110(4): 182-185.
54. **Bokor, Z.** 2012. Integrating Logistics Cost Calculation into Production Costing, Acta Polytechnica Hungarica 9(3): 163-181.
55. **Goudarzi, M.; Stonis, M.** 2014. Logistic controlling of field assembly, ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb 109(1-2): 46-49.

An Innovative Approach to Monitoring the Synergies of Extraordinary Events in Rail Transport

E. Nedeliakova[1], A. Kuka[2], P. Sulko[3], M. Hranický[4]

[1]*University of Žilina, Univerzitná 1, 01026, Žilina, Slovakia, E-mail: eva.nedeliakova@fpedas.uniza.sk*
[2]*University of Žilina, Univerzitná 1, 01026, Žilina, Slovakia, E-mail: kuka.adrian@gmail.com*
[3]*Železnice Slovenskej republiky, Klemensova 8, 81361, Bratislava, Slovakia, E-mail: sulko.peter@zsr.sk*
[4]*University of Žilina, Univerzitná 1, 01026, Žilina, Slovakia, E-mail: hranicky@atlas.cz*

Abstract

The definition of synergies in rail transport conditions is specific. The article discusses an innovative approach to monitoring the quality of services with acceptance of integration and emerging synergies in extraordinary operation in the sense of customer orientation. The synergy effects of the cooperation of railway undertakings in dealing with extraordinary situations can positively but also negatively influence customer decisions on future service usage. The proposal for an innovative approach is based on the typology of synergic effects according to Goold and Campbell, which have a quantitative and qualitative effect on the quality of services. The article characterizes a new software solution. It defines the distribution of synergy effects in the rail transport application. The aim is to support a sustainable transport system in the future, where a customer satisfaction is first and foremost.
KEY WORDS: *synergy, extraordinary events, rail transport*

1. Introduction

Synergy is the combined power of a group of things when they are working together that is greater than the total power achieved by each working separately [14].

The term synergy is used very often in the current management theory and practice. It has become popular both in common speech and the texts of economists, politicians, sociologists and representatives of other social and natural sciences disciplines. Some of the authors associate synergies with a series of unanswered questions about the behavior of management systems, especially when examining the behavior of senior executives and their teams [1]. Some theorists emphasize even "magic" and a remarkable place of synergy in modern management [11]. Corning defines synergy as combined or cooperative effects that are created by two or more particles, elements, parts or organisms - effects that cannot be otherwise obtained [3].

This paper deals with important results of research that emphasizes the importance of considering synergic effects of extraordinary events in rail transport.

Synergy is the difference between the social effect and the sum of individual effects, where the combined effect results from the interaction of groups of people, factors, or forces. Synergism is a phenomenon or a process where two or more discrete factors (influences, factors) act together to create an overall effect that is greater than the sum of the partial effects that would arise without the interaction of the factors considered [11]. The Mania Economics Server asserts that the term synergy means the synergy, co-operation, or joint action of the system components (components) resulting in a result that is greater than the simple sum of the component parameters [13].

2. The Synergy of Extraordinary Events in Rail Transport

The issue of synergy in rail transport is a broad concept, and it is important to assess how it can be expressed and described. It is essential to capture the essential elements and neglect as it applies to the creation of each model [2]. An example was chosen for the synergy in accident event (see Fig. 1), which is divided into accident procedures, removing an accident and customer impact. The graphical form was consulted with practitioners, whether it is clear, and any possible risks were derived from each drawing. In such a form it is compatible with the requirements of practice.

An extraordinary event is defined by the following general principle, such as the event has to meet the three criteria: unpredictable, unavoidable and external or internal cause [12]. It means that extraordinary events in the understanding of the research are the circumstances in the railway operation that arose due to disturbance of rolling stock, wagons, security devices, suicide or various stochastic influences. A definition that meets the criteria for rail transport states that such circumstances have three basic principles as shown in the Fig. 2.

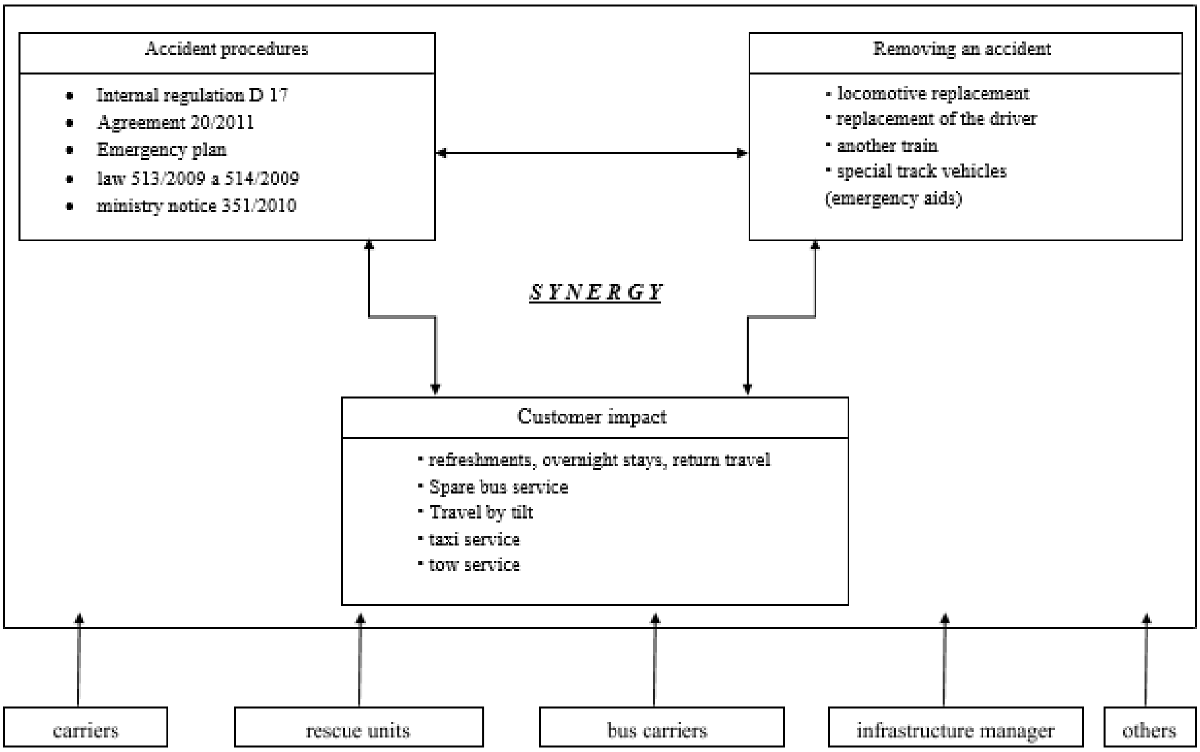


Fig. 1 Example of synergy in accident event

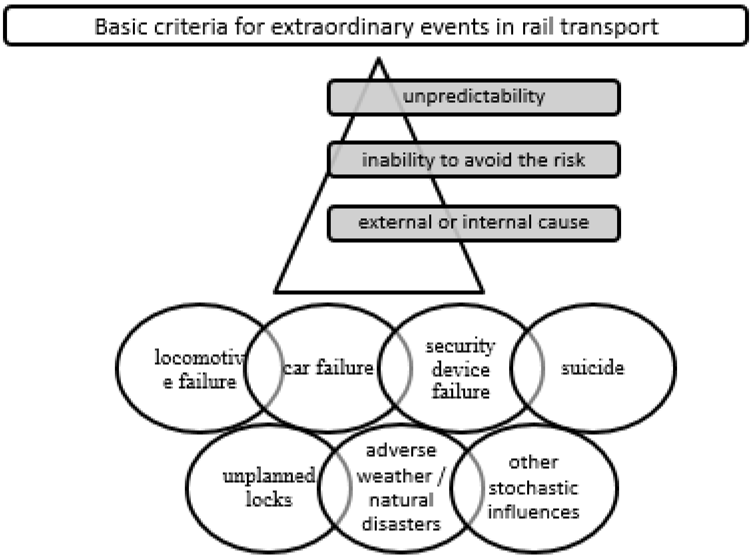


Fig. 2 Criteria for extraordinary events in rail transport

3. The Typology of Synergic Effects According to Goold and Campbell, Research Methods and Results

According to Goold and Campbell, the synergic effects can be divided into two dimensions, such as integration type synergies and emergence type synergies.

The synergy of the integration type belongs to the synergy whose effects can be evaluated quantitatively. It results from the co-operation of at least two sub-processes of different levels of management of railway undertakings [4]. These are processes that can be objectively monitored using, for example, statistical methods of quality management. Designing and using synergies of the integration type and its effects is foreseen in the required timeframe.

The basic idea for creating models of synergic effects of the integrative type is to allocate (allocate) or redistribute (reallocate) the activities and resources of the considered subsystems and use them in favour of the complete functioning of the systems that these subsystems form [11].

Synergy of emerging type represents the type, where the resulting effects are totally or significantly different from those of the subsystems. Goold and Campbell, in one of their publications, state that "the results of emerging effects are

reflected in the characteristics, behavioural abilities and the results of the system of managerial work considered as a whole".

The punctuality in passenger railway transport is very desired and related to customer satisfaction [10]. The research showed also a share of total delays, which can be considered as integration type of synergies, in rail passenger transport in total number of cases in % and minutes in %, with the results calculated over the entire year 2017 (Fig. 3).

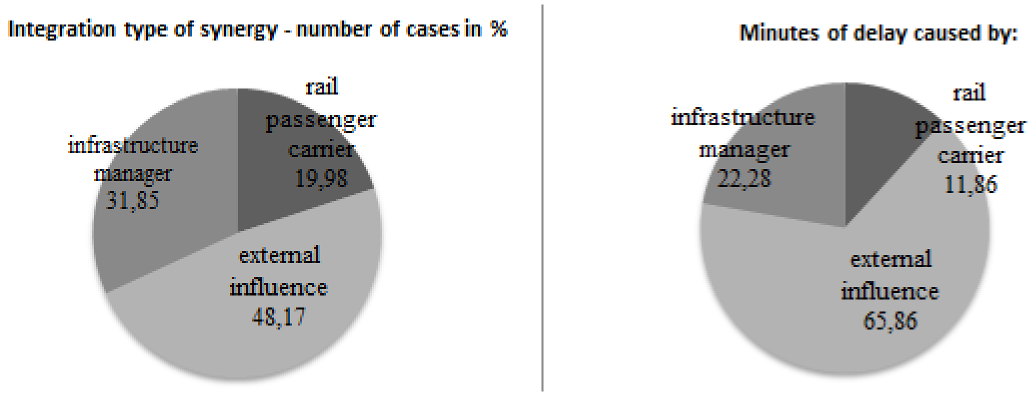


Fig. 3 Share of total delays in rail passenger transport in 2017

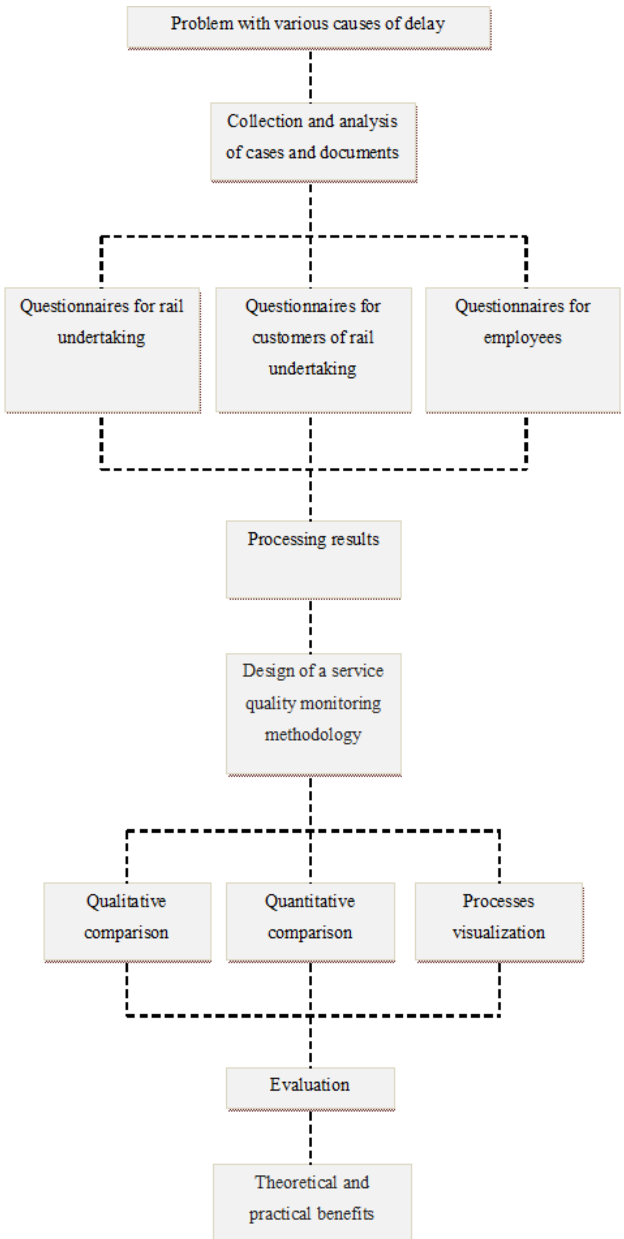


Fig. 4 Monitoring synergies following Grönroos model

Synergies in the quality of rail transport services represent an extremely broad issue. Synergic effects have been during the research defined for both normal and extraordinary operations, with specific examples but this paper is focused on extraordinary events [6, 5]. Exceptional events in rail transport bring many synergy effects. During the research, there was evidence that railway undertakings in Slovakia and abroad are monitoring extraordinary events statistically, carriers and infrastructure managers separately, often with various terminations of investigations, various employee penalizations, and inadequate adherence to the principles of continuous improvement of service quality customer relationship.

An innovative approach to monitoring the synergies of extraordinary events in rail transport comes from the design of a service quality monitoring interface, defining the synergies of service quality in rail transport. The essence is the basis of linking the Grönroos model quality criteria to the technical and functional dimension, while respecting the synergic effects of integration and emergent type [7].

The original Grönroos model characterizes these two quality dimensions:

- technical dimension that includes quantifiable quality criteria that can be measured objectively; it is a set of criteria that express the scope of the service delivery scenario;
- functional dimension that expresses the way the service is provided, this dimension is a subject to more subjective service quality assessment.

Following Grönroos model approach and integration and emergent type of synergies, the innovative approach to monitoring synergies was created as it is described in the next Fig. 4.

The result of linking the Grönroos model and two types of synergy is the design of software support to monitor service quality for the purpose of conducting an internal audit of both normal operation and extraordinary operation. The software serves as a clear and simple support for quality tracking results. It is divided into a part of monitoring the customer's view and the other monitoring employees in terms of bottom-up management. The data generated are based on the Grönroos application validation in the conditions of rail passenger transport. The effort was to create a simple software application that users, internal audit staff, will be able to use for quality monitoring [8].

4. Conclusion

Monitoring the quality of services in terms of customer satisfaction is currently in rail passenger transport, after the liberalization of the transport market, a very current issue. The resulting emergent type synergistic effects, which relate more to perceiving the quality of services by subjective viewing, often have a discontinuous course. They can even have a breakthrough character, i.e. pass from positive effects to negative and vice versa [8].

In practice, this means that each transport is unique, unrepeatable, and its perception of customers is influenced in various ways during normal and extraordinary operations.

Therefore research methods and results come from these mentioned ideas. The Graphical User Interface software was designed as a research solution. This interface allows to control an electronic device using a set of interactive pixels. Research has been done to test the interconnection of individual components in the application to follow and has been supplemented with the necessary data. The programming language was C ++ with the Qt extension, as one of the most widespread multiplatform.

An innovative approach to monitoring synergies in extraordinary events in rail transport is based on the definitions of integration and emergence synergies. The software was designed to monitor failures in the quality of rail operation both from the point of view of employees and customers. Developing the synergies of each railway undertaking, including their interactions with the business environment, is a prerequisite for further development of organizational prosperity, stability and entrepreneurial potential. These facts are valid for the point of view of emerging consequences, it means the consequences of a "soft" character, when the approach of the railway undertaking during extraordinary events, influences customer's credibility [9].

Acknowledgement

This paper is a result of the project KEGA 010ŽU-4/2017 New methods of teaching quality management in the study program Railway transport with a focus on optimization of extraordinary events in terms of customer orientation and the project VEGA 1/0019/17 Evaluation of regional rail transport in the context of regional potential with a view to effective use of public resources and social costs of transport.

References

1. **Abramović, B.; Brnjac, N.; Skrinjar, J.P.** 2014. Railway industrial track as the last mile in supply chain management, Proceedings of the second international conference on traffic and transport engineering (ICTTE), Belgrade: 890-897.
2. **Abramović, B.; Škrinjar, J.P.; Šipuš, D.** 2016. Analysis of railway infrastructure charges fees on the local passengers lines in Croatia: 918-923.
3. **Corning, P.A.** 2003. Nature´s Magic. Synergy in Evolution and the Fate of Humankind, Cambridge: Cambridge University Press.
4. **Ilgakojytė-Bazarienė, J.; Lebeckas, J.; Keršys, R.** 2016. Quality of Public Transport Service in Kaunas. 20th International Conference on Transport Means, Kaunas: 648-652.

5. **Keršys, R.; Bazaras, Z.** 2005. Evaluation of interaction of a passenger wagon and track. 9th International Conference on Transport Means, Kaunas: 255-258.
6. **Majerčák, P.; Majerčáková, E.** 2016. Measuring the Quality of Rail Services in the Slovak Republic, 20th International Conference on Transport Means, Kaunas: 688-693.
7. **Nedeliaková, E.; Sekulová, J.** 2016. Evaluation of quality in railway transport. University of Žilina.
8. **Nedeliaková, E.** 2017. KEGA 010ŽU-4/2017 New methods of teaching quality management in the study program Railway transport with a focus on optimization of extraordinary events in terms of customer orientation. University of Žilina.
9. **Nedeliaková, E. et al.** 2014. Services in railway passenger transport and its evaluation by dynamic models, Transport means 2014: 227-230.
10. **Štefancová, V.; Škorupa, M.; Kendra, M.** 2017. Utilization of Six Sigma Methodology in Terms of Reducing Train Delays, Proceedings of 21st International Scientific Conference Transport Means, Lithuania: 373-376.
11. **Vodáček, L.; Vodáčková, O.** 2009. Synergie v moderním managementu. Praha: Management Press, s. r. o.
12. Draft list of extraordinary circumstances. Available from: http://ec.europa.eu/transport/themes/passengers/air/doc/neb-extraordinary-circumstances-list.pdf
13. Princíp synergia [online cit.: 2018-05-20]. Available from:https://managementmania.com/sk/princip-synergia
14. Synergy [online cit.: 2018-05-20]. Available from: http://dictionary.cambridge.org/dictionary/english/synergy

Analysis of Torque Distribution in Ball-Screw Mechanisms under Extreme Temperature Conditions

I. Penkov

Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia, E-mail: igor.penkov@ttu.ee

Abstract

The article discusses load and torque distribution in ball-screw mechanisms. The ball-screw durability depends on friction forces and stress conditions between balls and grooves of the screw or the nut. Radial deformations of mechanism components change pressure angle that influences maximum load value. Unevenness of thermal deformation due to friction in the ball-screw and radial deformations due to temperature difference aggravate the load conditions and influences work quality of the mechanism.
KEY WORDS: *ball-screw, load distribution, torque, temperature, deformations*

1. Introduction

Coaxial ball screw mechanisms have been widely used in modern machinery to convert rotary motion to linear motion or torque to thrust, and vice versa. The constructive principle of such mechanisms provides presence of balls between screw and nut threads. The balls are closed along the nut length by help of a re-circulating mechanism [1]. Ball screws are made with one two or three return tubes. Each of those return tubes closes 2 – 4 threads [2]. In some special high-loaded ball-screws can be used one return tube on 9 – 10 threads [3].

Efficiency of a ball-screw mechanism depends on many parameters like materials of mechanism components, nut design, contact conditions between balls and mechanism components etc. In real practice, the reliability of ball-screws depends on environmental conditions that sometimes can be very aggressive and sometimes screws work under extremely low or high temperatures. Temperature influence on ball-screw mechanism work arises a great interest of scientists in the last decade [4, 5 and other]. There were analyzed deformations in radial and axial directions in separate mechanisms as well as in the linear motion systems as a whole.

Temperature influence on a ball-screw work quality can be considered by two criteria: influence of the environmental temperature and the heat generated by mechanism components. The last one criteria considers the heat generated by bearings and the heat generated between balls and screw and between balls and nut. The heat generated between balls and raceways of mechanism components can be presented as [6, 7]

$$G = 0.12\pi \cdot f_0 \cdot v_0 \cdot n \cdot M \,, \tag{1}$$

where f_0 - factor depended on nut type and lubrication method; v_0 - kinematic viscosity of lubricant; n - screw angular velocity; M - friction torque.

Temperature distribution depends on torque values and convective heat transfer coefficient along the ball-screw and nut surfaces. The last one can be presented as follows [8]:

$$h = \frac{0.133\, Re^{2/3}\, Pr^{1/3}\, k}{d} \,, \tag{2}$$

where Re – Reynolds number; Pr – Prandtl number; k – thermal conductivity of the surrounding air; d – diameter of the screw shaft.

Torque between balls and grooves of the nut and the screw depends on elasticity of the components and on the load distribution. The last one can be described by hyperbolic cosine low [9] and difference between most and lowest loaded ball rows is five and more times. Intensity of load distribution $q(z)$ can be found from condition of common deformations and calculated separately for different loading types. Ball-screws are usually loaded both tensile and compressed forces [10, 11] and in this case, the calculation of load distribution should be done on base of Eq. (3)

$$q(z) = \frac{\pm e^{(b\mp a)z}}{\gamma(b \pm a)} \cdot \left[\frac{F_4}{E_1 A_1} - \frac{F_3}{E_2 A_2} \right] \pm \frac{e^{(\pm H \mp z)a}}{\beta \cdot \sinh bH} \left[\frac{F_1 - F_4 e^{(b\mp a)H}}{E_1 A_1} - \frac{F_2 - F_3 e^{(b\mp a)H}}{E_2 A_2} \right] \cdot \left(b \cdot \cosh bz \mp a \cdot \sinh bz \right), \tag{3}$$

where a, b, β, γ are coefficients depending upon mechanical properties of material and geometrical parameters of threads and joints as a whole; $e \approx 2.71$ is the basis of natural logarithm; z is current co-ordinate of the nut height. H is the nut height; A is cross-sectional area of the screw or the nut; E is modulus of elasticity of the screw or the nut material; F_3 and

F_4 are axial forces applied accordingly to the nut and the screw in the cross-section $z = 0$; F_1 and F_2 are axial forces applied accordingly to the screw and the nut in the cross-section $z = H$. The lower signs correspond to the scheme of loading when the compression force act on the screw.

Pressure angle changes along the nut height though the maximum increase $\Delta\alpha$ is less than 2° [12]. In this case, the load distribution is changed insignificantly (only 0.5%) but the contact points of balls and screw parts will be changed and this fact causes increasing of friction [13]. Common design can be calculated by general mathematical methods and analyzed taking into account manufacturing processes [14]. It is established experimentally [1, 15] that with increasing of axial forces the efficiency of ball screws decreases. At explanation of this phenomena is necessary to take into account not only increasing of contact area between balls and screw elements but also distribution of tangential forces that cause the balls friction.

2. Torque in Ball-Screws

As a common case of ball screws can be considered (Fig. 1) stretched nut and compress-stretched screw [11]. The nut is moved along the screw axis in inverters of rotation motion into linear and on base of the nut motion, the screw will be deformed variously. Values of internal forces F' and F'' are changed during the motion and can be found from condition of common deformations and initial condition $F = F' + F''$. Taking into account dependency of forces F' and F'' on their location on the screw, the initial conditions of calculation will be $F' = F$, $F'' = 0$ at $z = 0$ and $F' = 0$, $F'' = F$ at $z = H$. If $z = H/2$ then $F' = F'' = F/2$.

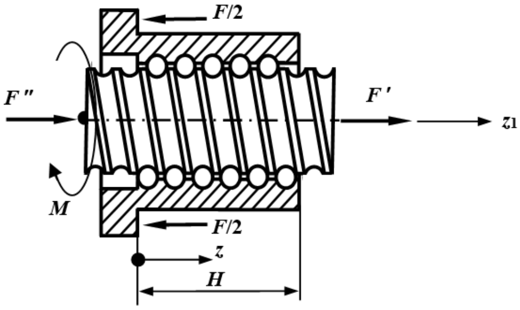


Fig. 1 Axial loads in the ball-screw

After integration of the Eq. (3) and expression of torque equation through axial forces, for the section $z = 0$ can be obtained the follows:

$$T = T' = \frac{Fd_2}{2\beta}\left[e^{a(H-z)}\frac{\sinh bz}{\sinh bH}\left(\frac{1}{E_1A_1}+\frac{e^{(b-a)H}}{E_2A_2}\right)-\frac{e^{(b-a)z}-1}{E_2A_2}\right]\cdot tan\left(\psi+\rho_n\right) \tag{4}$$

and for the section $z = H$ as the following:

$$T = T'' = \frac{Fd_2e^{a(z-H)}}{2\sinh bH}\left[b\cdot\cosh bH + a\cdot\sinh bH\right]\cdot\tan\left(\psi+\rho_n\right), \tag{5}$$

here d_2 is pitch diameter of the screw; ψ is lead angle; ρ_n is friction angle.

Torque is changed according to change of axial loads at nut motion from $z = 0$ to $z = H$ and can be obtained by equation:

$$T = \xi T' + \left(1-\xi\right)T'', \tag{6}$$

where ξ is proportional ratio between F' and F''.

If $z = H/2$, the torque can be found as half of the sum of Eqs. (5) and (6).

Let us to consider the changing of torque values along of the nut height on base of a universal ball screw SX/BX [1]. The screws have six different diameters with pitch $P = 5$ mm. Torque distribution is shown in Fig. 2. From the figure can be seen that with decreasing of screw diameter difference between limit values of the torque increases. The maximum torque in the screw 63 × 5 is 22% of full torque value and in the screw 20 × 5 this value has already 43%. Taking into account the limit dynamical load 91.7 kN and 14.5 kN [1] is possible to obtain torque $T_{63} \approx 79.2$ Nm and $T_{20} \approx 11.2$ Nm accordingly. It also is necessary to mark that difference between limit values of the torque will be somewhat more than is shown in Fig. 2 as with increasing of load on the balls the contact area will increase as well as the values of tangential forces. Above calculated torques will be created by forces $F_{63} \approx 2.7$ kN and $F_{20} \approx 1.4$ kN. In this case some balls will move with sliding and increase the friction. If the screw pitch will not be changed and diameter of the screw will decrease,

the amount of „sliding” balls will increase. The value of limit torque can be obtained after solving of Eq. (7) together with the Eq. (6) of the work [16]. From this solution can also be found the limit axial load on the screw.

$$q_1(z_1) = \frac{(1-\varepsilon)\cdot F \cdot e(h_1 - z_1)\cdot a_1}{\sinh b_1 h_1}\left[b_1 \cosh b_1 z_1 - a_1 \sinh b_1 z_1\right], \tag{7}$$

where ε is a factor of load distribution, $0 \le \varepsilon \le 1$.

Values of maximum and minimum torques for screws with four, five and six threads are shown in Fig. 3. The difference between these values increases with increasing of the thread numbers but the absolute value of the maximum torque decreases. For example, for the screw 25 × 5 this decreasing is 7% and for the screw 50 × 5 already 20%. In the screw of SX/BX 63 × 5 with six working threads, the maximum torque is less than minimum torque in the same screw with four working threads.

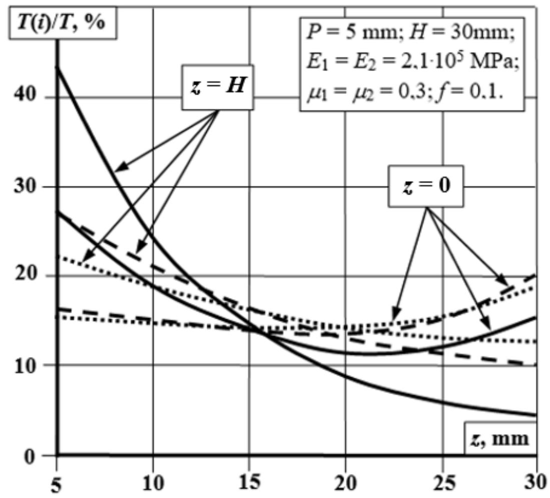


Fig. 2 Torque distribution along the nut in the drive SX/BX. ——— SX/BX 20 × 5; – – – SX/BX 40 × 5; ·········· SX/BX 63 × 5

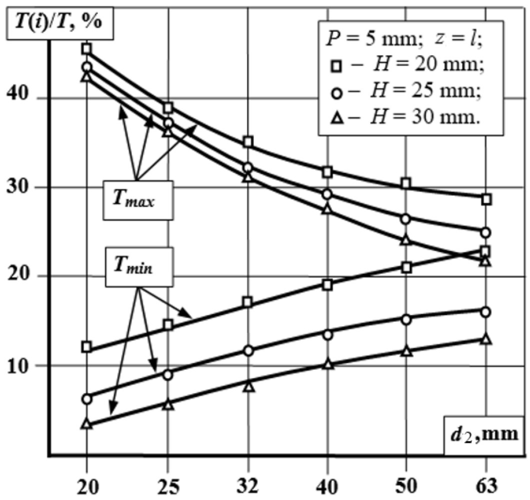


Fig. 3 Limit torque on the nut groovs in the drive SX/BX

3. Deformation of the Boll-Screw Components

As it was noted above, the torque distribution in ball-screws depends on load distribution between balls and the last one depends on deformations of screw, nut, and balls. With increasing of the unevenness of the torque distribution, the unevenness of friction forces increases. This process leads to increasing of the ball-screw wear and to increasing of temperature unevenness in the drive. Increasing or decreasing of working temperature causes radial deformations of the screw drive parts and this aggravates stress conditions of mechanism components and decreases durability of the system as a whole.

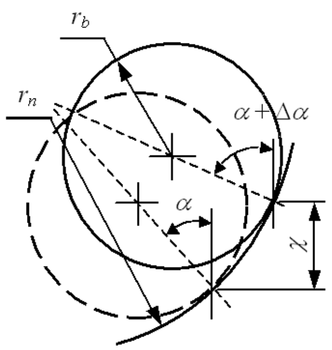


Fig. 4 Displacement of contact point between ball and thread

Displacement of the contact point between the ball and the groove can be presented as follows

$$\chi = \delta_f + \delta_\mu + \delta_c + \delta_T, \tag{8}$$

where δ_f is axial displacements of grooves due to the radial deformations from pressure on the groove flank, δ_μ; radial displacement depending upon axial displacement; δ_c is axial component of contact deformations; δ_T is thermal

deformation.

On the other hand the value χ can be presented as difference of pressure angles α and $\alpha + \Delta\alpha$ (Fig. 4).

$$\chi = \left[\cos\alpha - \cos\left(\alpha + \Delta\alpha\right)\right] \cdot r_n , \tag{9}$$

where r_n is minor radius of the thread profile in normal section.

The change of pressure angle can be found by solving of the Eqs. (8) and (9)

$$\Delta\alpha = \cos^{-1}\left[\cos\alpha - \frac{\delta_f + \delta_\mu + \delta_c + \delta_T}{r_n}\right] - \alpha , \tag{10}$$

where $\delta_f = \frac{p \cdot d_c \cos\alpha}{2E}(1-\mu)$; $\delta_\mu = \frac{\sigma \cdot d_c \cdot \mu}{2E}$; $\delta_c = 0.977\sqrt[3]{\frac{2}{r_b}\left(\frac{p}{E}\right)^2}\cos\alpha$; $\delta_T = k \cdot \Delta T \cdot d_c$; p is pressure on the ball; d_c is diameter of the contact between the ball and the screw or between the ball and the nut; μ is Poisson's ratio; σ is normal stress; r_b is ball radius; k is linear temperature expansion coefficient; ΔT is temperature difference.

4. Conclusions

Uneven load distribution between threads in a ball-screw mechanism causes uneven torque distribution. Equations for torque calculation depending on type of loading are given. It is shown that torque distribution can be described by hyperbolic equations. With decreasing of the screw diameter the difference between limit torque values increases. For universal ball-screws SX/BX 63 × 5 the maximum torque is 22% of full torque value and in the screw 20 × 5 this value will already be 43%. The number of the working threads significantly influences on the torque distribution. The difference between maximum and minimum torque magnitudes increases with increasing of the thread numbers but the absolute value of the maximum torque decreases. Uneven load and torque distribution causes uneven friction forces and temperature in the ball-screws. Working temperature differences aggravate loading process.

Acknowledgements

This research work was supported by innovative Manufacturing Engineering Systems Competence Centre IMECC (supported by Enterprise Estonia and co-financed by the European Union Regional Development Fund, project EU48685).

References

1. SKF Ground Ball Screws. Available from: www.skf.com
2. Design of High-Speed Ball Screw Drives. Available from: www.ina.com
3. Tsubaki ball screw for heavy load. Available from: http://www.tsubaki.com/ballscrew.htm
4. **Yang, A.S.; Cai, S.Z.; Hsieh, S.H.; Kuo, T.C.; Wang C.C.; Wu, W.T.; Hsieh, W.H.; Hwang, Y.C.** 2013. Thermal Deformation Estimation for a Hollow Ball Screw Feed Drive System, Proceedings of the World Congress on Engineering 2013 Vol III, WCE 2013, July 3-5, London, U.K.
5. **Min, B.K.; Park, C.H.; Chung, S.C.** 2016. Thermal Analysis of Ballscrew Systems by Finite Difference Methods, Transactions of the Korean Society of Mechanical Engineers 40(1): 41-51.
6. **Tian, R; He, R.** 2004. Solution for Heating of Ball Screw and Environmental Engineering, World Manufacturing Engineering and Market 3: 65-67.
7. **Verl, A.; Frey, S.** 2010. Correlation between feed velocity and preloading in ball screw drives, Ann. CIRP59 2, 429-432.
8. **Xu, Z.Z.; Liu, X.J.; Kim, H.K.; Shin, J.H.; Lyu, S.K.** 2011. Thermal error forecast and performance evaluation for an air-cooling ball screw system, International Journal of Machine Tools and Manufacture 51(7-8): 605-611.
9. **Birger, I.A.; Iosilevich, G.B.** 1990. Threaded and Flanged Joints. 3rd Edition, Machine-building, Moscow.
10. The Tensioning of Lead Screw with Rolling Bearing Supports. Available from: www.ina.com
11. Types of Loading. Available from: www.roton.com
12. **Penkov. I.; Aleksandrov D.** 2011. Axial Displacements in Ball Screw Mechanisms with Two and Four Contact-point, International Review of Mechanical Engineering 5(7): 1213-1218.
13. **Pinegin, S.V.** 1976. Rolling Friction in Machines and Devices. Mechanical Engineering, Moscow.
14. **Sharkov O.V.; Koryagin S.I.; Velikanov N.L.** 2018. Shaping Cutter Original Profile for Fine-module Ratchet Teeth Cutting, IOP Conference Series: Materials Science and Engineering, Vol. 327, 042102. doi:10.1088/1757-899X/327/4/042102.
15. **Pyasik, I. B.** 1962. Ball Screws. Moscow – Kiev, Mashgiz.
16. **Orlov, A.V.** 2003. Limit Torque, causes Loses of Contact in Ball Bearings, Russian Engineering Research 9: 32-36.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Innovative Concepts of Systems Modelling in the Tactical Air Force

E. Augustyn[1], A. Kadziński[2]

[1]*Poznań University of Technology, Piotrowo 3, 60-695 Poznań, Poland,*
E-mail: emil.augustyn@doctorate.put.poznan.pl
[2]*Poznań University of Technology, Piotrowo 3, 60-695 Poznań, Poland, adam.kadzinski@put.poznan.pl*

Abstract

The wide dissemination of systems methodology has been observed in almost every branch of human activity for recent decades. It proves that systemic approach is the most common and universal way of researching the surrounding world from the holistic point of view. The science and technology development has been generating outright ideal situation which causes that the human possibilities of designing and creating new man-made systems seems to be unlimited. The constant evolution of particular human activity branches – that could constitute scientific areas of interests – induces scientists to make attempts to describe them in the most innovative and understandable way using, among others, the following tools: systems methodology, systems engineering and object-oriented approach (facility-oriented approach). The authors of this paper on the basis of the literature analyses and their own experiences present innovative concepts of systems models that concern the branch of tactical air force based on an example of the Polish Tactical Air Force current state of affairs. The starting point for the following considerations is established by the matrix of the five-levels model of Generalized Technical System (GTS), whose basic element is constituted by any technical object (facility). The authors, using the mentioned GTS matrix and having considered a tactical aircraft as a leading technical object in the tactical air force, also including organizational structures and other systems, objects and components of this area of interests, present the model of technical Tactical Air Force System (TAFS). The TAFS model is mainly focused on operators' organization and operation systems of a military combat tactical aircraft. However, the TAFS model fundamentally constitutes a kind of metamodel because it includes component objects, systems and structures which could be also presented by different models. Due to that, during the further considerations there is presented the possibility of detailed description and development a fragment of one TAFS level of decomposition that presents the Tactical Aircraft Operation Systems. The authors via next innovative model describe the Tactical Aircraft Operating System (TAOS) – system of aircraft operational usage – as a part of the Tactical Aircraft Operation System on the third level of the TAFS decomposition. The model of TAOS constitutes a kind of model of an anthropotechnical system that is a part of the aforementioned metamodel. The innovativeness of the TAOS model derives from its presentation by the authors in a form of an aggregated analyses domain of the tactical aircraft operational usage. This kind of aggregated analyses domain consists of seven single analyses domains and each of them covers a series of processes, operations and events related to airmen's aviation activities cycles. Using the above-mentioned approach gives the possibility of a detailed, clear and coherent description of the TAOS. The application of systems methodology, object-oriented approach, technical object systems engineering and using the concept of the aggregated analyses domain to describe the systems found in the tactical air force, constitutes only an example of innovative possibilities to formal description this area of interests. The above-mentioned approach, tools and concepts also indicate the further directions of these systems development.
KEY WORDS: *model of Generalized Technical System, technical objects (facilities), technical objects systems engineering, metamodel of Tactical Air Force System, model of Tactical Aircraft Operating System, airman's aviation activities cycle, aggregated analyses domain*

1. Introduction

The continuous development of the whole aviation industry, especially in the field of the military aviation [13], determines the increasing need of more and more adequate and innovative way of formal description of this area of interests. A complex organizational structures of military aviation systems, their component systems, objects (facilities), components or relations that exist between all of them have already been significantly extensive. Due to that, they require their own representation in a form of models which could be used for various types of scientific researches or analyses. Every kind of model of an aviation system constitutes a layout that reflects or recreates the functioning of aeronautical organizational structures, objects or components with the required approximation in relation to the real state. Generally the main purpose of a model is to capture an essence of a given system. What is more, a process of a model construction (modelling) should be considered as a process that allows scientists to examine relationships existing in the particular system. The modelling constitutes a process of selecting the system elements that are characterized by essential features due to the adopted criteria for the model and the cognitive process. The knowledge that concerns laws which govern within occurring processes, operations or events, as well as data derived from the all-embracing experience, allow to determine the structure of a model and inner relations that occur within it. During the modelling process it is very often necessary to implement kind of simplifications/generalizations in relation to

the reality. It is usually connected with the intention of the future model implementation within a wider range of variables, objects, circumstances, situations, branches, etc.. Additionally, in order to carry out a scientific research of a large and complex system it is worthwhile to use the concept of metamodel that means the model which includes models connected with the chosen area of interests.

The main purpose of the following paper is to present innovative concepts of systems models in a tactical air force [1, 12] area of interests. The following models were developed on the basis of the Polish Tactical Air Force [7, 13] current state of affairs that is concerned as an example of the tactical air force. The authors have developed the metamodel of technical **Tactical Air Force System** (**TAFS**) described in that paper [1]. Notwithstanding the fact, that in theoretical considerations presented in [1], the TAFS is considered mainly as the technical system [9, 11], in fact it constitutes a kind of a social engineering system. It is caused by the fact that the TAFS despite of inanimate technical elements, also includes elements of the organizational structure and human resources. The TAFS metamodel reflects the extensive structure of the tactical air force, which is considered as the main area of interests of this paper. The considerable size of this structure and the legitimacy of considering it as a metamodel is evidenced by the fact that at each of the five decomposition levels of this metamodel there are elements that could be presented by a model. This fact causes an opportunity of creation a kind of model that includes models – the metamodel. As an example, the authors present the model of **Tactical Aircraft Operating System** (**TAOS**) as one of the TAFS component systems at the level of Tactical Aircraft Operation Systems [1]. The innovativeness of the above-mentioned and presented models results from tools and concepts that were used to develop them. What is more, these tools and concepts have never been used before in the area of interests related to the tactical air force.

2. Tactical Air Force System (TAFS)

The model of **Generalized Technical System** (**GTS**) (Fig. 1) presented in that paper [2] is established as a kind of starting point to the considerations and description of the TAFS model. The GTS constitutes a kind of comprehensive tool that collects and connects systems, objects and their components that participate in a particular area of interests, from a technical point of view.

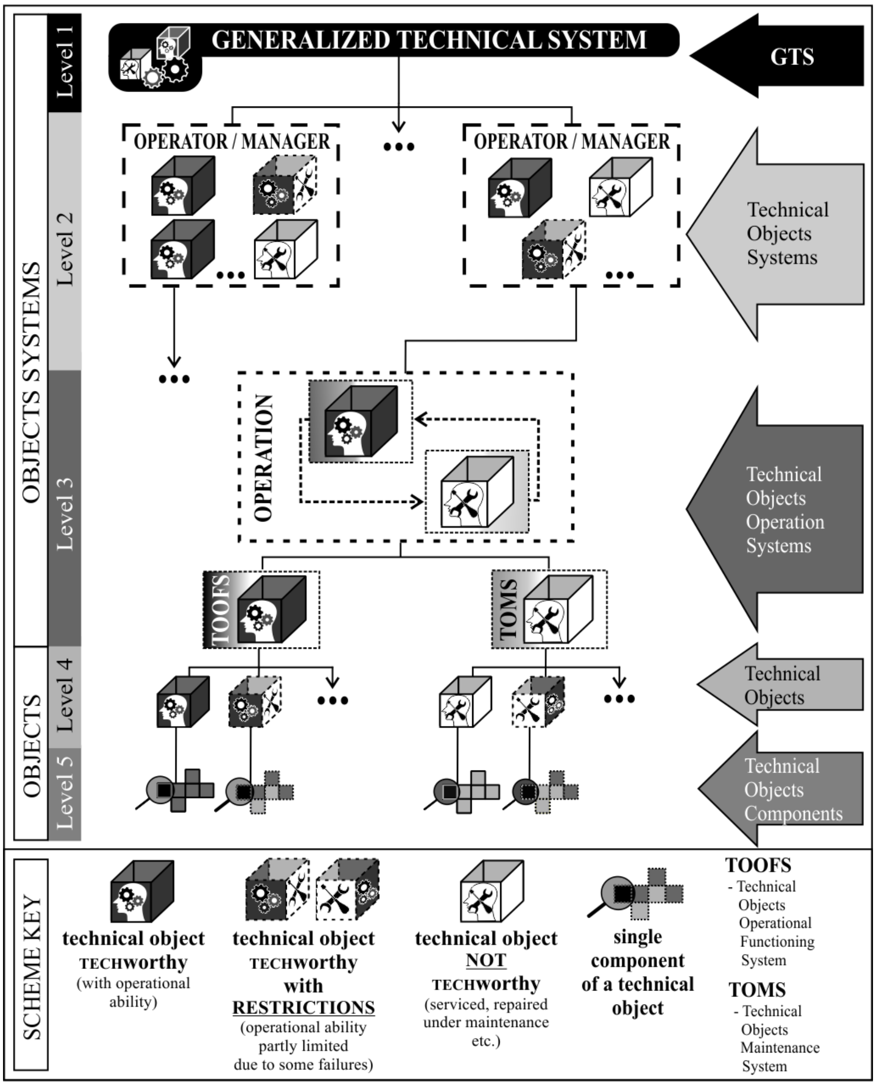


Fig. 1 Schematic diagram of the model of Generalized Technical System [2]

The tree-shaped scheme of the GTS model decomposition preserves the general rules of organizational taxonomy of any operator/manager (Fig. 1) of technical objects. In addition, it also presents – in a general way – the technical objects operation process (Fig. 1), organizes the technical objects according to their reliability state criteria (Fig. 1) and extracts components of technical objects (Fig. 1). It is assumed, that the term of technical object [11] means every kind of vehicles, equipment, devices or parts of infrastructure that are related to a given area of interests from a technical point of view.

The **Tactical Air Force System** means the military entity that constitutes an aggregation of the following synergistically connected elements: hierarchical organizational structure, flying & maintenance staff and military combat aircraft treated as complex technical objects (facilities) – all these elements altogether participate in the operation process [1]. The tree-shaped metamodel of TAFS (Fig. 2), which was introduced and described in [1], constitutes a kind of new comprehensive approach to the structure of one of the systems which functions in the air force. The TAFS metamodel consists of five levels of decomposition which present the Tactical Air Force System (level 1) from the level of Tactical Air Wings (TAWs) [1] with subordinate Tactical Air Force Bases (TAFBs) [1] as an organizational level (level 2), through the level of Tactical Aircraft Operation Systems (level 3) to the levels of a single tactical aircraft (level 4) and its components (level 5). What is more, the TAFS metamodel also includes characteristic features (variables and parameters) of this system. In addition, the TAFS metamodel reflects the Polish Tactical Air Force by the structure in which a tactical aircraft as the technical objects constitute the dominant elements.

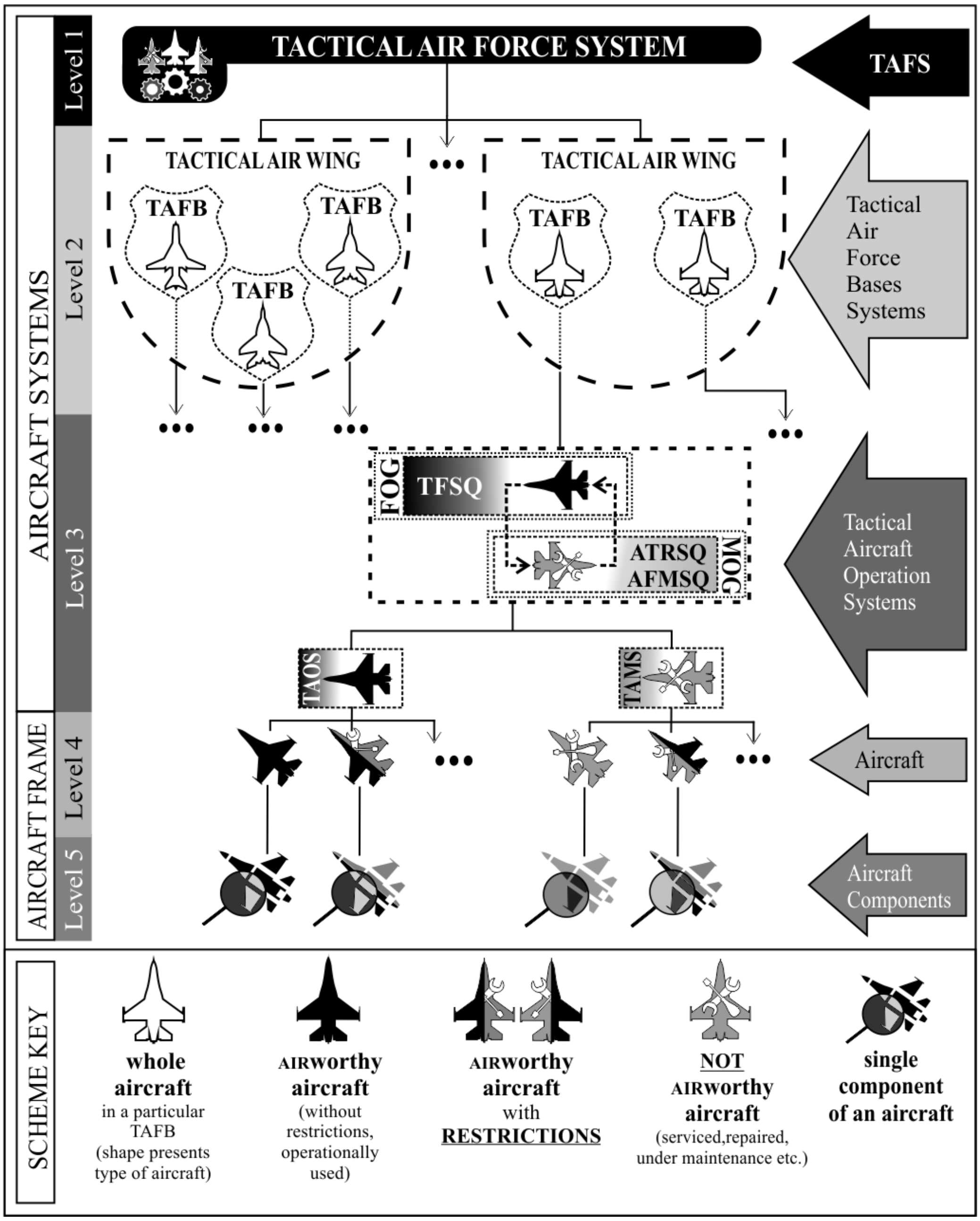


Fig. 2 The metamodel of Tactical Air Force System (TAFS) divided into five levels of decomposition [1] (used abbreviations are explained in the text of this paper)

The innovativeness of the TAFS metamodel results from the concept of the model matrix derived and known from the GTS model, as well as from the applied designing tools that have been used during the modelling of the system. Using the tools such as the systems methodology [4], general systems engineering [4] and object-oriented (facility-oriented) approach [11] resulted in the metamodel of the new system, that technically, organizationally and functionally connects existing systems, objects and components of this area of interests. What is more, military principles of hierarchy and subordination are preserved simultaneously. During the designing process of the TAFS metamodel, the scheme of technical systems simplified designing process [1, 2] was applied. The entire process of the TAFS designing is classified as the technical objects systems engineering [2] that constitutes some sort of peculiar systems engineering. As a result, the fragment of tactical air force structures was transformed into the metamodel. Comparing the schematic diagrams of the models presented in Figs. 1 and 2, there are easy noticeable obvious homologies between them.

3. Tactical Aircraft Operating System (TAOS)

The **Tactical Aircraft Operating System** (system of tactical aircraft operational usage) is one of the systems among the Tactical Aircraft Operation Systems in the tactical air force (e.g. Polish Tactical Air Force). It is assumed, that is the anthropotechnical system which constitutes a detailed development of one part (level 3) of the TAFS metamodel. The level 3 of the TAFS metamodel (Fig. 3) concerns the Tactical Aircraft Operation Systems. This level presents the general and simplified scheme of tactical aircraft operation on the basis of the complex analyses of the aircraft operation state of affairs [11] in the TAFBs. The tactical aircraft operation follows a complex operation process [8] in a predefined aircraft operation system [1, 8] which mainly consists of two states – operating (usage) and maintenance [8].

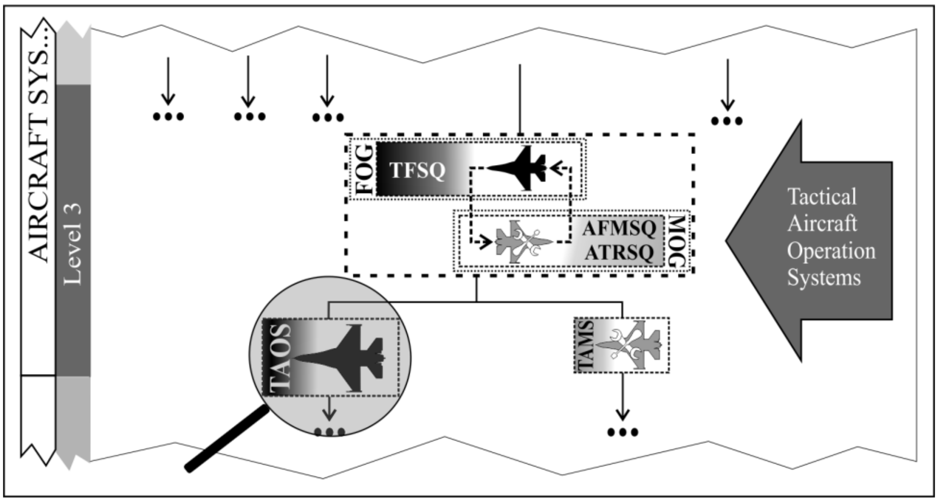


Fig. 3 Level 3 of the TAFS metamodel that indicates the location of the TAOS model (used abbreviations are explained in the text of this paper) – own scheme based on [1]

The aircraft operating in the TAFB takes place directly in the **Tactical Flying Squadron**s (**TFSQ**s – Fig. 2, Fig. 3) [1] which operate as a structural part of the **Flying Operations Group** (**FOG** – Fig. 2, Fig. 3) [1]. The military flying staff [5] (airmen) from the FOG/TFSQs with the airworthy aircraft or aircraft airworthy with restrictions (aircraft reliability states – Fig. 2, Fig. 4) constitute main elements of the TAOS. The **Tactical Aircraft Maintenance System** (**TAMS** – Fig. 2, Fig. 3) [1] mainly consists of not airworthy aircraft or aircraft airworthy with restrictions and military Aerospace Engineering Staff (AES) [6] divided into maintenance squadrons. The maintenance squadrons – the **Aircraft Flightline Maintenance Squadron**s (**AFMSQ**s – Fig. 2, Fig. 3) [1] and the **Aircraft Technical Repair Squadron**s (**ATRSQ**s – Fig. 2, Fig. 3) [1] – operate as a part of the **Maintenance Operations Group** (**MOG** – Fig. 2, Fig. 3) [1]. The TAMS and other systems in the TAFS environment are appointed to support the TAOS, treated as the main system in the TAFS.

The innovativeness of the TAOS model (Fig. 4) results from the used concept of the model, which is presented in a format of an aggregated analyses domain (Table). The aggregated analyses domain of the TAOS consists of seven disjointed, individual analyses domains that are ordered in time (Table, Fig. 4). Each of the analyses domain constitutes the sequence of processes that integrate specific operations and events related to the airman's aviation activities cycle (AAAC) [3] which includes the air mission (defined as in that paper [3]) and during its time the tactical aircraft operating cycle (cycle of aircraft operational usage) is performed. The aircraft operating is defined as an individualized relationship between an airman and an aircraft. The subsequent individual analyses domains are connected to each other by an airman-aircraft anthropotechnical pair. Basically, only five from (that are included into the air mission – Table, Fig. 4) the seven analyses domains are closely related to the essential (primary) aircraft operating (aircraft operating cycle – Table). The remaining two analyses domains are associated with the air mission(-s) preparations and summaries. They are added to the model, basically connected with aircraft operation, due to the intention of providing a full picture of issues related to the aircraft operating in the tactical air force.

Table

General table shape of the TAOS in a format of the aggregated analyses domain

AGGREGATED ANALYSES DOMAIN	**TACTICAL AIRCRAFT OPERATING SYSTEM (TAOS)**						
	ANALYSES DOMAINS						
	DOMAIN I (PRE-) AIR MISSION PREPARATIONS	**DOMAIN II** BEFORE TAKE-OFF	**DOMAIN III** DEPARTURE	**DOMENA IV** AIR TASK	**DOMAIN V** ARRIVAL	**DOMAIN VI** AFTER LANDING	**DOMAIN VII** (POST-) AIR MISSION SUMMARIES
		AIR MISSION					
		AIRCRAFT OPERATING CYCLE					

The TAOS model also could be considered as a metamodel due to the fact that within the processes including their operations and events in subsequent analyses domains there could be extracted e.g. the model of airman's aviation activities cycle (AAAC) [3] or the model of series of airmen's aviation activities cycles (SAAAC) [3]. Both mentioned cycles (AAAC and SAAAC) are strictly connected with the aircraft operating (aircraft operational usage by airmen). As a stage of the air mission an airman makes the flight [3, 10] whose the most important phase is to perform the air task [3] or several air tasks. Performing the air tasks is the main goal of the TAOS. Air tasks are performed by airmen during the air missions that constitute an essential part of the single AAAC. The airmen who take part in the aviation work shift [3] carry out single AAACs that make up the SAAAC (models of AAAC and SAAAC are described in details in that paper [3]).

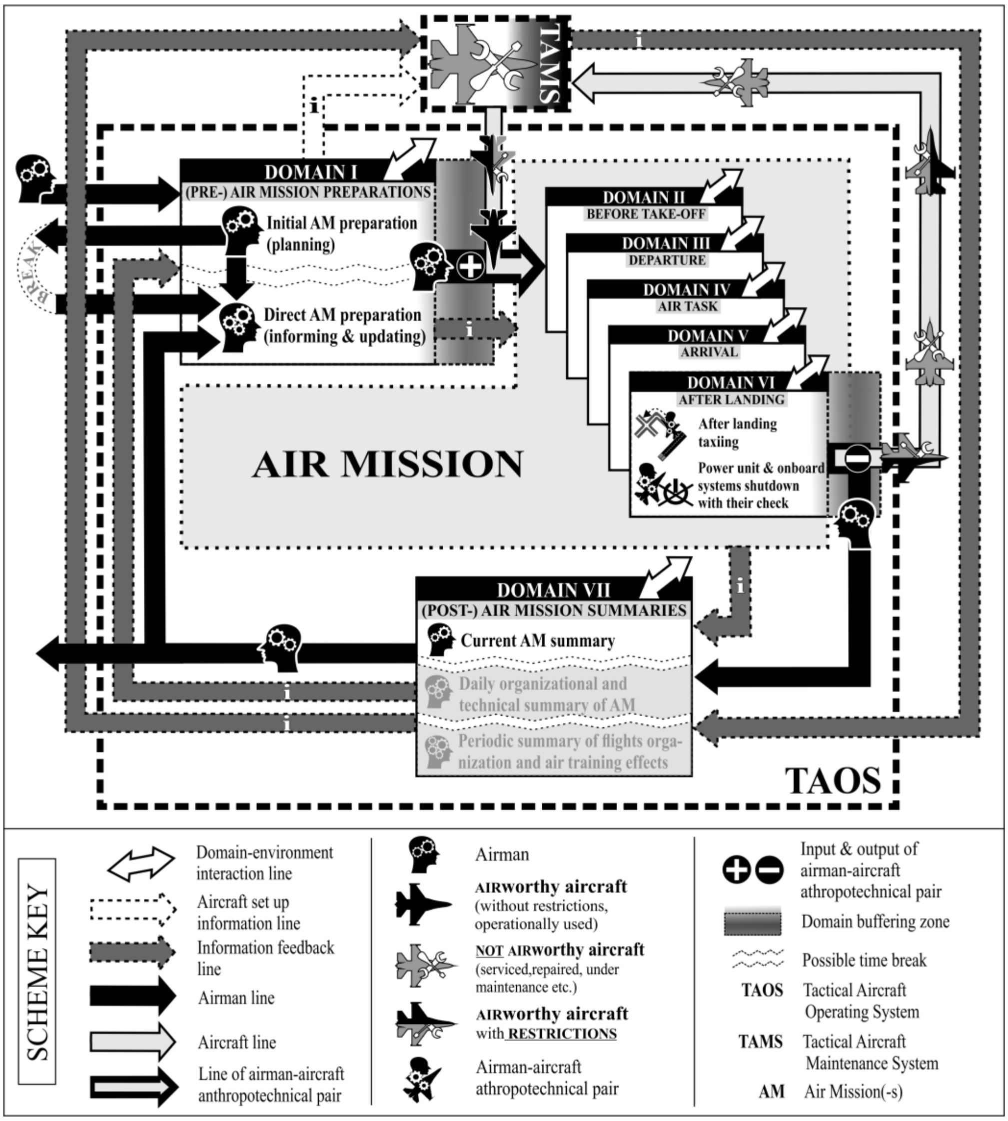


Fig. 4 Model of the Tactical Aircraft Operating System in a format of the aggregated analyses domain

The introduced method of modelling the aircraft operating system provides the desired generality, comprehensiveness, coherence and transparency of such the model, that allows to its implementation for various types of tactical aircraft and TAFBs. In principle, within the presented considerations, the model is described in relation to the single aircraft operating cycle that is carried out by one airman during the one air mission. However, the authors took care of such a shape of the model, that allows to its implementation in more complex aircraft operating cycles (more than one aircraft and more than one airman) which often occur in practice.

4. Conclusions

The application of the tools such as systems methodology, general systems engineering, technical objects systems engineering, object-oriented approach and the use of the concept (format) of the aggregated analyses domain to describe systems found in the tactical air force is only an example of innovative possibilities of formal description the tactical air force. The use of these tools and concepts is the first official attempt of their implementation in relation to the considered area of interests. In this way, further directions for the development of considered systems, especially the systems included into the TAFS metamodel, are also outlined. The presented format of the Tactical Aircraft Operating System model can be successfully applied, e.g. to the modeling of the Tactical Aircraft Maintenance System. Moreover, the matrix of the model concerning the Generalized Technical System, which was applied to develop and present the Tactical Air Force System, can be successfully implemented to the modeling of other aviation systems and structures that exist in the military aviation.

The above authors' considerations were aimed at exemplifying the application of the aforementioned tools and concepts in the field of systems modeling in the selected area of interests. In this way, starting from the model of Generalized Technical System, through the model of Tactical Air Force System, the authors received the general, coherent and transparent model of Tactical Aircraft Operating System. The final model in the above presented format can be successfully used as the aggregated analyses domain for the processes that concern the assessment of the risk of threats which are generated in the Tactical Aircraft Operating System. The risk of threats assessment in each of the single analyses domains will finally lead to the comprehensive risk of threats assessment in the entire Tactical Aircraft Operating System.

Acknowledgements

The research work financed with the means of statutory activities of Faculty of Machines and Transport Poznań University of Technology No. 05/52/DSPB/0280.

References

1. **Augustyn, E.; Kadziński, A.** 2017. Systemic approach and model of the Polish Tactical Air Force, Journal of KONES Powertrain and Transport 24(2): 7-16, DOI: 10.5604/01.3001.0010.2889.
2. **Augustyn, E.; Kadziński, A.** 2017. Model of Generalized Technical System, Journal of Mechanical and Transport Engineering 69(3): 5–13, DOI: 10.21008/j.2449-920X.2017.69.3.01.
3. **Augustyn, E.; Kadziński, A.** 2018. Models of airmen's aviation activities cycles in the Tactical Aircraft's Operating System, Journal of KONBIN 1(45), p. unknown, in print.
4. **Cempel, C.** 2008. Teoria i inżynieria systemów - zasady zastosowania myślenia systemowego: dla studentów wydziałów politechnicznych, Wydawnictwo Naukowe Instytutu Technologii i Eksploatacji, Radom.
5. **Dowództwo Generalne Rodzajów Sił Zbrojnych (MON).** 2016. Regulamin lotów lotnictwa Sił Zbrojnych Rzeczypospolitej Polskiej (RL-2016), Warszawa.
6. **Dowództwo Generalne Rodzajów Sił Zbrojnych (MON).** 2017. Instrukcja służby inżynieryjno-lotniczej lotnictwa Sił Zbrojnych Rzeczypospolitej Polskiej (ISIL-2017), Warszawa.
7. **Grenda, B.** 2014. System walki Sił Powietrznych Rzeczypospolitej Polskiej, Ementon, Warszawa.
8. **Lewitowicz, J.** 2006. Podstawy eksploatacji statków powietrznych. Tom 3. Systemy eksploatacji statków powietrznych, Instytut Techniczny Wojsk Lotniczych, Warszawa.
9. **Łunarski, J.** 2010. Inżynieria systemów i analiza systemowa, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów.
10. **Milkiewicz, A.** 2009. Praktyczna aerodynamika i mechanika lotu samolotu odrzutowego w tym wysokomanewrowego, Instytut Techniczny Wojsk Lotniczych, Warszawa.
11. **Młyńczak, M.** 2012. Metodyka badań eksploatacyjnych obiektów mechanicznych, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.
12. NATO Standarization Agency. 2014. NATO Glossary of Terms and Definitions (AAP-6), Brussels.
13. **Zabłocki, E.** 2007. Siły powietrzne, Akademia Obrony Narodowej, Warszawa.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Material Deliveries Rationalization by Utilizing the Specific Designed Methodology

M. Chovancova[1], O. Stopka[2], M. Hlatka[3]

Institute of Technology and Business in České Budějovice, Okružní 517/10, 370 01 České Budějovice, Czech Republic,
E-mail: [1]chovancova@mail.vstecb.cz, [2]stopka@mail.vstecb.cz, [3]hlatka@mail.vstecb.cz

Abstract

The article outlines the option to streamline material deliveries by utilizing the specific methodology regarding the amount and size of deliveries rationalization designed within this research study. Factors have been suggested based on their influence on overall transport and material costs as well as risk of delivered material shortage. The article describes the proposed methodology related to the identification of the suitable material replenishment method as well. In the final part of the article, the particular case study related to the research issue is indicated.
KEY WORDS: *regularity delivery, material replenishment, rationalization, streamlining, methodology*

1. Introduction

Deliveries rationalization is an important field of company logistics from the several reasons. One of the main reasons is the fact that the stored material binds the substantial finances of the enterprise (10-25% of total assets) and also that its storage and maintenance requires to undertake the specific expenditures (10-20% of total costs), which may have a positive or negative impact on the economy of the enterprise.

Apart from the economic point of view, there is another important aspect that is taken into consideration when deciding about the stored material. This aspect is called the level of customer service which is an important factor within the competitiveness and position of the enterprise on the market. The customer service includes the observance of the delivery period, reliability, accuracy and flexibility, which represents the level of coverage of the random requirements. The level of material in the store needs to be kept as low as possible in order not to exhaust the capital, however at the same time, as high as possible in order the company is able to cover the unexpected fluctuations, either in production or in the market.

From the aforementioned, it is obvious that the enterprise need to look for the optimal level of the material in the store in order to ensure the continuity of production at reasonable costs and reasonable tying up of capital in the material. From that reason, it is important to take into account the various factors that affect the material level. The aim of this paper is to propose the methodology that takes into consideration a set of factors affecting the material level.

2. Methodology to Determine the Suitable Material Replenishment Method

Explicit and reliable identification of appropriate method of the material replenishment, on the basis of determined factors, represents the objective of the proposed methodology. The factors determined on the basis of the factors affecting the identification of appropriate method of the material replenishment represent the foundation for the creation of the particular methodology. They are shown in Table 1. The existing models of deliveries rationalization: 1. Material Value and Regularity Delivery Analysis and the model of economic order quantity (the "EOQ model") are the background for the proposed methodology [1-3].

Table 1

Determining the factors of proposed Methodology of the deliveries rationalization

Factors affecting a the material replenishment	Reflected factors within the methodology
tying up of capital in the material	material value
the risk that the acquired material will not be used	nature of the consumption
the risk of delivered material shortage	
material consumption	annual consumption (Q)
material storage and maintenance costs	storage costs (C_{ST})
acquisition costs	delivery costs (C_A)
short delivery time	delivery times (T_D)
deliveries in the exact time sequence	delivery reliability (DR)
deliveries of the exact amount of material	delivery precision (DP)
deliveries in the required quality	delivery quality (DQ)

Source: authors

On the basis of the Material Value and Regularity Delivery Analysis, all items of the material in a store are divided into two groups. The first group consists of the material types that are suitable for the continuously replenishment or for replenishment into the storage (A, B, C, D, E, F). The second group consists of the material types that are, on the basis of the two above mentioned models, suitable for the replenishment into the storage or for the random replenishment (G, H, I). The proposed methodology continues by the calculation of the order period (td) for each material item. The period of the delivery cycle, corresponding to the optimal delivery (by the Harris - Wilson's formula) is calculated according to the formula (1) [3-5]:

$$t_d = \frac{\sqrt[T]{\dfrac{2 * C_A * Q}{T * C_{ST}}}}{Q}\left[\text{days}\right], \tag{1}$$

where C_A - costs per one order of the specific material item (delivery costs) (€); Q - annual need of the material item (pcs/other units), or planned consumption (delivery costs); T - the planning period during which the planned consumption Q is considered (days); C_{ST} - storage costs of the material unit per time unit (one day).

Based on this data, the material items of the first group (method of continuously replenishment/replenishment into the storage), created in the previous section of the methodology (Material Value and Regularity Delivery Analysis), are divided into two groups [6, 7]:

1. material items group suitable for the method of continuously replenishment - short-time order period (within 1 week);
2. material items group suitable for the replenishment into the storage - other material items that do not meet the conditions of method of continuously replenishment.

Material items of the second group, created in the previous section of the methodology (Material Value and Regularity Delivery Analysis), are divided into two groups as well (replenishment into the storage/random method of material replenishment):

1. material items group suitable for the random method of material replenishment - long-time order period (over 90 days),
2. material items group suitable for the replenishment into the storage - delivery costs (costs per one order of the specific material item = delivery costs) are higher than the storage costs.

And thus, three material groups were established similarly to the Material Value and Regularity Delivery Analysis. The consideration of the factors value and character of consumption as well as the criterion of delivery costs, storage costs and annual consumption represent the difference compared to the Material Value and Regularity Delivery Analysis. In the next step, the groups suitable for continuously and random methods of replenishment are more detailed analyzed.

Within the proposed methodology, in its next section, the material items of the group intended (suitable) for the random replenishment method, created in the previous section of the methodology (calculations based on the model EOQ) on the basis of assessment of the particular suppliers delivery times appropriateness, are divided into two groups [8-10]:

1. material items group suitable for random method of material replenishment - satisfactory delivery time of the specific material item particular supplier for the random method of replenishment (since, the random method of replenishment is carried out after the generating the material need, shorter delivery times are more appropriate);
2. material items group suitable for replenishment into the storage - unsatisfactory delivery time of the specific material item particular supplier for the random method of replenishment.

Within the section of the methodology, where calculations are performed based on the EOQ model, when using the continuous analysis of the items supplier of such material group which is intended for the continuously replenishment method, the material items are divided into two groups [9, 10]:

1. material items group suitable for continuously replenishment method,
2. material items group suitable for replenishment into the storage.

This distribution is realized based on the analysis of delivery reliability (DR), delivery precision (DP) and delivery quality (DQ) using the following formulas (2-4) [11-13]:

$$DR = \frac{\text{value of the material delivered on time}}{\text{total value of the delivered material}}; \tag{2}$$

$$DP = \frac{\text{value of the delivered material}}{\text{value of the ordered material}}; \tag{3}$$

$$DQ = \frac{\text{value of the received material}}{\text{value of the delivered material}}. \tag{4}$$

On the basis of the calculations results, the material items, within each analysis, are divided into three groups. It

is shown in Table 2 below. Material items included into the third group, even in a single analysis, are considered to be a part of a material group suitable for replenishment into the storage [14].

Table 2

The inclusion of material into group on the basis of supplier evaluation

	1. group	2. group	3. group
Fulfillment of the criterion	90-100%	80-90%	0-80%
Group (DR/DP/DQ)	1/4/7	2/5/8	3/6/9

Source: authors

Procedure of the individual consignments assignment for each delivery method is described utilizing the following steps:

1. Sectionalizing consignments into groups (A-I) according a principles of the following table (Table 3).
2. Calculation the optimal length of delivery for individual consignment according to the Eq. (1) and selection into the two groups:
   - *short-time delivery period:* t_d = ‹1;30›;
   - *long-time delivery period:* t_d = ‹31;∞).
3. Calculation the delivery reliability for individual consignment according to the Eq. (2) and selection into the groups 1-3:
   - 1. group: *DR* = ‹0,9;1›;
   - 2. group: *DR* = ‹0,8-0,9›;
   - 3. group: *DR* = ‹0;0,8›.
4. Calculation the delivery precision for individual consignment according to the Eq. (3) and selection into the groups 4-6.
   - 4. group: *DP* = ‹0,9;1›;
   - 5. group: *DP* = ‹0,8-0,9›;
   - 6. group: *DP* = ‹0;0,8›.
5. Calculation the delivery quality for individual consignment according to the Eq. (4) and selection into the groups 7-9.
   - 7. group: *DQ* = ‹0,9;1›;
   - 8. group: *DQ* = ‹0,8-0,9›;
   - 9. group: *DQ* = ‹0;0,8›.

Table 3

The inclusion of material into group on the basis of supplier evaluation

	HIGH CONSIGNMENT VALUE	**AVERAGE CONSIGNMENT VALUE**	**LOW CONSIGNMENT VALUE**
REGULAR DELIVERY	[A] *continuously replenishment*	[B] *continuously replenishment*	[C] *continuously replenishment/into the store*
DELIVERY FLUCTUATIONS	[D] *continuously replenishment*	[E] *continuously replenishment/into the store*	[F] *continuously replenishment/into the store*
RANDOM DELIVERY	[G] *replenishment into the store/random*	[H] *into the store /random*	[I] *into the store/random*

Source: authors

3. Benefit-Risk Assessment of the Proposed Methodology of the Delivery Rationalization

The consideration of a large number of factors represents the substantial difference of the proposed "Methodology of the Delivery Rationalization" compared to the existing models. This fact results in a more reliable determination of the replenishment method. In addition, compared to the existing models, the clear replenishment method is established on the basis of the proposed Methodology of the Delivery Rationalization [15, 16].

The benefits of the proposed methodology may be expressed in the following two fields:

1. storage costs savings;
2. reduction of risk of delivered material shortage.

Storage Costs Savings

In the case of favorable conditions, the possibility of the material level reduction compared to the material level in a store after the application of the Material Value and Regularity Delivery Analysis that may occur after the taking into consideration the storage costs, delivery costs and annual consumption represents the benefit of the proposed "Methodology of the Delivery Rationalization". Based on these factors, continuously replenishment (frequent deliveries and relatively low quantities) or random replenishment (long-time delivery period after the need arises) may be profitable for the enterprise. As long as these material items meet the factors taking into account the suppliers, the release of finances and storage costs reduction will represent the acquired outcome [14].

Compared to the existing models, the higher storage costs savings and the lower tying up of capital in the material will be achieved in such case when the items F have such costs and such annual consumption that, based on the model EOQ, it is more effective for the enterprise the material replenishment at more frequent intervals (up to 1 week) and relatively low amounts. The similar example may also occur in the case of group items of C and E for which the Material Value and Regularity Delivery Analysis does not specify the unambiguous replenishment method [17, 18].

A similar situation may occur if there is such an material item of group G, H or I, of which the optimum order quantity and the order period, after the application of EOQ model, are suitable for the random replenishment method [19].

The following table (Table 4) shows an example of a situation where a material input has such features that, using the "Methodology of the Delivery Rationalization" for the determination of the appropriate replenishment method, may bring the storage costs savings for the enterprise.

Table 4

Example of the costs savings

<table>
<tr><th rowspan="2">Factors
Metodology</th><th rowspan="2">Material group</th><th colspan="3">t_d</th><th rowspan="2">DR</th><th rowspan="2">DP</th><th rowspan="2">DQ</th><th rowspan="2">DT</th><th rowspan="2">Replenishment method</th></tr>
<tr><th>Q</th><th>C_{ST}/day</th><th>C_A/1del</th></tr>
<tr><td>Material value and regularity delivery analysis</td><td>F</td><td colspan="3"></td><td colspan="4"></td><td>into the store</td></tr>
<tr><td rowspan="2">Methodology of the delivery rationalization</td><td rowspan="2">F</td><td colspan="3">1.5</td><td rowspan="2">1 (2)</td><td rowspan="2">4 (5)</td><td rowspan="2">7 (8)</td><td rowspan="2">-</td><td rowspan="2">continuously</td></tr>
<tr><td>175200 pcs</td><td>3mu</td><td>2mu</td></tr>
<tr><td>Material value and regularity delivery analysis</td><td>G</td><td colspan="3"></td><td colspan="4"></td><td>into the store/ random</td></tr>
<tr><td rowspan="2">Methodology of the delivery rationalization</td><td rowspan="2">G</td><td colspan="3">96</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">OK</td><td rowspan="2">random</td></tr>
<tr><td>200pcs</td><td>8mu</td><td>55mu</td></tr>
</table>

Explanatory notes: mu – del - delivery; monetary units; pcs – pieces

Source: authors

$$t_d^F = \frac{365 * \sqrt{\dfrac{2*2*175\,200}{365*3}}}{175\,200} = 1.5 \text{ days} \tag{5}$$

$$t_d^G = \frac{365 * \sqrt{\dfrac{2*55*200}{365*8}}}{200} = 96 \text{ days} \tag{6}$$

Reduction of Risk of Delivered Material Shortage

Reduction of risk of delivered material shortage by taking into consideration the other three factors - delivery precision, delivery quality and delivery times as well (besides the nature of the consumption and the delivery reliability, which the "Decision-cube" takes into account) represents another benefit of the proposed "Methodology of the Delivery Rationalization" [13, 17].

The greatest risk of delivered material shortage occurs during the continuously replenishment. For the enterprise, the material items of group A, B and D are significant in terms of turnover share. Therefore, it is very important so that they are always available. These items are characterized by the high values as well. Due to the tying up the finances, their level should be minimized. Therefore, factors of the suppliers - delivery reliability, delivery precision and delivery quality - are taken into account in the proposed "Methodology of the Delivery Rationalization". Delivery precision is also taken into account in the context of "Decision-cube", however, it ignores the other two factors, which are also important for the continuously replenishment. [20, 21].

One of the factors relating to the suppliers is taken into account within the material items of group G, H and I. In

the case that, even after the taking into consideration the storage costs, delivery costs and the annual consumption, these material items are potentially suitable for the random replenishment, the delivery time of their supplier will be taken into account [22]. The following table (Table 5) shows an example of the reduction of risk of delivered material shortage.

Table 5

Example of the reduction of risk of the inventory deficiency

<table>
<tr><th rowspan="2">Factors / Methodology</th><th rowspan="2">Material group</th><th colspan="3">t_d</th><th rowspan="2">DR</th><th rowspan="2">DP</th><th rowspan="2">DQ</th><th rowspan="2">DT</th><th rowspan="2">Replenishment method</th></tr>
<tr><th>Q</th><th>C_{ST}/day</th><th>C_A/1del</th></tr>
<tr><td>Decision-cube</td><td>D</td><td colspan="3"></td><td>1. group</td><td colspan="3"></td><td>partially suitable for continuously replenishment</td></tr>
<tr><td rowspan="2">Methodology of the delivery rationalization</td><td rowspan="2">D</td><td colspan="3">-</td><td rowspan="2">1 (2)</td><td rowspan="2">5 (6)</td><td rowspan="2">8 (9)</td><td rowspan="2">-</td><td rowspan="2">into the store</td></tr>
<tr><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Material value and regularity delivery analysis</td><td>I</td><td colspan="3"></td><td colspan="4"></td><td>into the store/ random</td></tr>
<tr><td rowspan="2">Methodology of the delivery rationalization</td><td rowspan="2">I</td><td colspan="3">96</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">OK</td><td rowspan="2">random</td></tr>
<tr><td>14600pcs</td><td>0.2mu</td><td>100mu</td></tr>
</table>

Source: authors

$$t_d^I = \frac{365 * \sqrt{\dfrac{2*100*14\,600}{365*0,2}}}{14\,600} = 96 \text{ days} \tag{7}$$

4. Conclusions

The number of factors that results in a more reliable determination of the replenishment method means a substantial difference of the proposed "Methodology of the Delivery Rationalization" compared to the existing models. Applying the proposed Methodology of the Delivery Rationalization causes the optimization of costs while reducing the risk of delivered material shortage. Proposed methodology, considering its structure, eliminates the disadvantages of the existing models, when, given the limited factors structure, there is an ambiguous determination of the material groups and thus the ambiguous determination of the replenishment method.

Moreover, previously used models have not taken into consideration the reduction of risk of delivered material shortage, or they have been taking into consideration it only marginally. “Methodology of the Delivery Rationalization”, with respect to the acceptance of the set of factors, also takes into account the aforementioned criterion, and thus can clearly identify the material group, and subsequently, the appropriate replenishment method.

References

1. **Kampf, R.; Lorincová, S.; Hitka, M.; Caha, Z.** 2016. The application of ABC analysis to inventories in the automatic industry utilizing the cost saving effect, Nase More 63(3): 120-125.
2. **Hlioui, R.; Gharbi, A.; Hajji, A.** 2015. Integrated quality strategy in production and raw material replenishment in a manufacturing-oriented supply chain, International Journal of Advanced Manufacturing Technology 81(1-4): 335-348.
3. **Ben-Daya, M.; As'ad, R.; Seliaman, M.** 2013. An integrated production inventory model with raw material replenishment considerations in a three layer supply chain, International Journal of Production Economics 143(1): 53-61.
4. **Kučerka, D.; Timko M.; Kmecová I., Kučerka M.** 2014. Material supplies in an enterprise and transport, Logi - Scientific Journal on Transport and Logistics 5(2): 20-27.
5. **Gong, D.C.; Lin, J.Y.; Lin, G.C.; Ma, W.N.** 2013. A Mathematical Model on an Economic Lot Scheduling Problem with Shifting Process and Joint Material Replenishment. 2013 IEEE International conference on industrial engineering and engineering management, Bangkok, Thailand 1: 1219-1222.
6. **Ližbetin, J.; Černá, L.; Ľoch, M.** 2015. Model evaluation of suppliers in terms of real company for selected criteria, Nase More 62: 147-152.
7. **Bertrand, JWM.; Zuijderwijk, M.; Hegge, HMH.** 2000. Using hierarchical pseudo bills of material for customer order acceptance and optimal materialreplenishment in assemble to order manufacturing of non-modular products, International journal of production economics 66(2): 171-184.
8. **Dukic, D.; Turkalj, D.; Bojmic, L.** 2009. Application of Computer-aided queuing simulation model in the rationalization of cereals delivery process, Proceedings of the 5th international congress flour-bread '09 and 7th creation con-

gress of cereal tehcnologists, Opatija, Croatia 5: 569-577.
9. **Sabo, A.; Tomic, Z.; Marusic, G.; Draskovic, D.; Varga, J.; Krajcir, I.** 2006. Drug rationalization at the clinics in university teaching centre Novi Sad: Introducing the delivery of daily doses of the drugs to hospital departments, Pharmacoepidemiology and Drug Safety 15(S1): S181-S181.
10. **Zhou, B.; Peng, T.** 2017. Just-in-Time Material Replenishment Scheduling in a Mixed-Model Assembly Line, 2016 International Conference on Multimedia Systems and Signal Processing, ICMSSP 2016; New Taipei, Taiwan 1: 115-118.
11. **Gašparík, J., Gáborová, V., Ľupták, V.** 2016. Process Portal for Railway Cargo Operator with CRM Support. Transport means 2016 - proceedings of the 20th international konference, Kaunas University of Technology 20: 245-249.
12. **Taleizadeh, A.A.; Moghadasi, H.; Niaki, S.T.A.; Eftekhari, A.** 2008. An economic order quantity under joint replenishment policy to supply expensive imported raw materials with payment in advance, Journal of Applied Sciences 8(23): 4263-4273.
13. **Zhou, B.-H.; Peng, T.** 2017. Scheduling methods of just-in-time material replenishment in mixed-model assembly lines, Kongzhi yu Juece/Control and Decision 32(6): 976-982.
14. **Majerčák, J.; Kudláč, Š.; Ponický, J.** 2016. Innovative management of supply chains, Logi - Scientific Journal on Transport and Logistics 7(1): 98-107.
15. **Shriram Kumaar Pandian, P.; Jose Ananth Vino, V.; Meenakshi, C.M.** 2014. Reduce cycle time through Kanban replenishment using streamlining materialflow, International Journal of Applied Engineering Research 9(22): 7814-7819.
16. **Yang, N.S.; Huang, C.Y.; Hou, M.-C.** 2013. Inventory-up-level joint replenishment model for re-working materials and new materials, Advanced Materials Research 711: 763-768.
17. **Wong, J.-T.; Chen, K.-H.; Su, C.-T.** 2009. Replenishment policy with deteriorating raw material under a supply chain: Complexity and the use of ant colony optimization. 3rd International United Information Systems Conference, UNISCON 2009; Sydney, NSW, Australia 20: 142-152.
18. **Hitka, M.; Potkány, M.; Hajduková, A.** 2011. Application production logistics to optimize material flows, Logi - Scientific Journal on Transport and Logistics 2(2): 27-37.
19. **Yanpirat, P.; Chettaisong, P.; Lalitaporn, P.** 2006. The economic joint replenishment inventory model of outsource materials with non-constant demand and unit purchase cost, 36th International Conference on Computers and Industrial Engineering, ICC and IE 2006; Taipei; Taiwan 36: 3699-3706.
20. **Bertrand, J.W.M.; Zuijderwijk, M.; Hegge, H.M.H.** 2000. Using hierarchical pseudo bills of material for customer order acceptance and optimal material replenishment in assemble to order manufacturing of non-modular products, International Journal of Production Economics 66(2): 171-184.
21. **Sung, J.C.; Gong, D.C.** 2008. An integrated production-inventory model for deteriorating production with defective item rework and joint material replenishment policy, Journal of the Chinese Institute of Industrial Engineers 25(4): 326-336.
22. **Čejka, J.; Bartušková, P.; Bartuška, L.** 2016. Application of mathematical methods in transport and logistic area. 15th Conference on Applied Mathematics 2016, APLIMAT 2016, Bratislava, Slovakia 15: 225-235

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Derivation of Crush Force versus Deformation Behaviour of Vehicles at Different Impact Speeds

S. Himmetoglu[1], K.B. Yilmaz[2], B. Yildirim[3], A. Tekin[4]

[1]*Hacettepe University, Beytepe 06800, Ankara, Turkey, E-mail: s.himmetoglu@hacettepe.edu.tr*
[2]*Hacettepe University, Beytepe 06800, Ankara, Turkey, E-mail: korhanbabacanyilmaz@gmail.com*
[3]*Hacettepe University, Beytepe 06800, Ankara, Turkey, E-mail: boray@hacettepe.edu.tr*
[4]*Hacettepe University, Beytepe 06800, Ankara, Turkey, E-mail: altasys18@gmail.com*

Abstract

Regulatory and consumer full-width rigid barrier (FWRB) crash tests can help to derive the crush force versus deformation behaviour of car structure and validate the finite element (FE) models of cars. However, the regulatory and consumer crash tests are performed at a specific impact speed and they are the only ones available for most researchers in the academia. In this study, the FE models of a 2010 year model passenger car and a 1997 year model van are validated successfully against the real crash test data regarding FWRB impacts at 40 km/h and 56 km/h. As real crash test data at higher impact speeds do not exist, higher speed FWRB crash tests are performed virtually using the FE models at impact speeds varying from 20 km/h to 88 km/h. As a result of the analysis presented in this study, crush force versus deformation characteristics of the car structure are obtained. Piecewise linear approximation of the crush force versus deformation curves are used in a lumped-mass model to obtain cheaply and accurately the key responses of the cars in FWRB impacts for a certain speed range. The derived crush-force versus deformation characteristics of the car front can be used in multi-body simulations of 100% overlap single vehicle impacts and two-vehicle head-on frontal collisions, thus reducing the number of costly crash tests.
KEY WORDS: *vehicle safety, finite element analysis, full-width rigid barrier impacts, vehicle stiffness*

1. Introduction

In regulatory and consumer crash tests, cars impact a fixed rigid barrier (i.e. fixed rigid wall) with 100% overlap (i.e. full-width) at a fixed impact speed which is 56 km/h in US New Car Assessment Program (US NCAP), 50 km/h in European New Car Assessment Program (EuroNCAP) and 40 km/h in Federal Motor Vehicle Safety Standards (FMVSS) compliance testing. The results of NCAP crash tests are made available to public. Researchers can download FMVSS compliance test and US NCAP crash test data from the website of National Highway Traffic Safety Administration (NHTSA) [1].

The data from full-width rigid barrier (FWRB) frontal impacts can be processed to obtain the crush forces acting on the car and the deformation of the car so as to produce crush-force versus deformation characteristics of the car structure. The frontal stiffnesses of cars can be determined by using these force-versus-deformation characteristics. Stiffness is an important parameter that determines the acceleration experienced by a car during impact, hence restraint systems must be designed taking stiffness into consideration. Knowing the force-versus-deformation characteristics of car structure is critical in crash simulations and accident reconstruction [2, 3]. However, crash tests are costly and they are mostly performed at a specific impact speed. Therefore, the derivation of force-versus-deformation behaviour from crash tests for a wide range of impact speed is very limited for academic researchers.

Availability of detailed finite element models of cars can help to estimate the behaviour of car structure at different crash severities. National Crash Analysis Center of the George Washington University constructed finite element (FE) models of a few number of cars through reverse engineering and these FE models can be downloaded from the website of NHTSA [1]. In this study, the FE models of a 2010 year model passenger car and a 1997 year model van are validated against real FWRB crash test data at impact speeds of 40 km/h and 56 km/h which are again obtained from the NHTSA crash test database [1]. Considering the high economic cost of real crash tests, the remaining FWRB impact tests at other speeds are performed virtually using LS-DYNA finite element program.

The derived crush-force versus deformation curves of the car structure as a result of this analysis, are mathematically modelled to obtain piecewise linear approximations which are used in a lumped-mass model of FWRB impact. The mathematically modelled crush force versus deformation characteristics can be used to interpolate key responses of the car at different impact speeds from the available crash test or simulation data.

2. FWRB Frontal Impact Tests and Test Data Processing

In consumer and regulatory frontal impact tests, cars impact a fixed rigid barrier with 100% overlap at a fixed impact speed as shown in Fig. 1. The aim of this test is to obtain information about vehicle crashworthiness and the performance of the restraint systems. The rigid wall is composed of load cells measuring the crush forces and moments

acting on the car as shown in Fig. 2. A typical example for the load cell matrix and its position with respect to the car front are depicted in Fig. 3.

Fig. 1 FWRB frontal impact test [1]

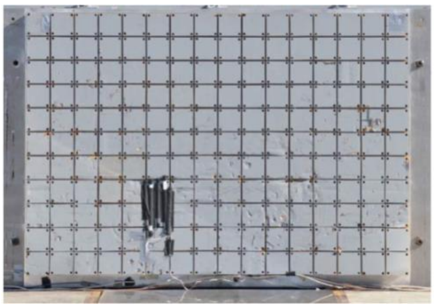


Fig. 2 Load cell wall [1]

Fig. 3 Locations of load cells relative to the car [1]

The total barrier force (i.e. crush force or wall force) is obtained by adding the individual forces measured by the load cells on the rigid barrier. However, the individual load cell forces are first filtered according to the Society of Automotive Engineers (SAE) Recommended Practice J211-1 [4]. In filtering these barrier forces, Channel Frequency Class 60 (CFC60) type filtering is used with a cut-off frequency of 100 Hz. The linear accelerations of the occupant compartment of the car are recorded by accelerometers which are typically attached symmetrically to the left-and-right rear sills, or left-and-right rear seats, or left-and-right rear floorpan. The occupant compartment linear accelerations are expressed in the x and z directions of the global coordinate system shown in Fig. 1. However, vehicle acceleration data need to be filtered before use. For comparison of vehicle crash performance, vehicle accelerometer data are filtered according to SAE J211-1 using CFC60 type filtering with a cut-off frequency of 100 Hz [4]. The linear displacement of the undeformed occupant compartment in the global x-direction is used to estimate the deformation of the car. Therefore, the occupant compartment linear acceleration in the global x-direction needs to be double integrated to find the displacement. According to SAE J211-1, vehicle acceleration data are filtered using CFC180 type filtering with a cut-off frequency of 300 Hz when vehicle acceleration data is to be used in integration for velocity and displacement. The filtered linear accelerations on the right and left side of the occupant compartment are averaged to obtain a single average occupant-compartment acceleration in the global x-direction which is then double integrated using trapezoidal rule to find the x-displacement and deformation of the car. Since the deformation of the car is based on the double-integration of accelerometer data, the term "dynamic deformation (or crush)" can be used to indicate the deformation of the car which changes during impact [3]. It should be noted that in FWRB impacts, there is typically a forward pitch of the car (see Fig. 1) and since the x-displacement of the car is derived from accelerometers attached to the rear of the car, the maximum deformation of the car is calculated from the crash test data with an excess. The time increment for the load cell and accelerometer data is typically 0.1 ms.

After having processed the sensor data as described above, the total barrier force is plotted against the displacement of the occupant compartment to obtain the overall force versus deformation characteristics of the structural elements of the car in frontal impact.

3. The Finite Element Model Details of the 2010 Year Model Car

In this section, the finite element model (FEM) of the 2010 year model car and its construction details are presented as an example. In order to validate the FEM, the computational approach results are first compared with the real FWRB frontal crash tests at impact speeds of 40 km/h and 56 km/h. Then, the FEM simulations for the FWRB frontal crash test are extended to study the response of the car at different impact speeds using LS-DYNA (2018) finite element program and LS-Prepost (2018) keyword manager program. The generated keyword files are solved by the LS-DYNA solver in ANSYS Mechanical APDL (2018) using distributed computing for INTEL MPI on a local workstation.

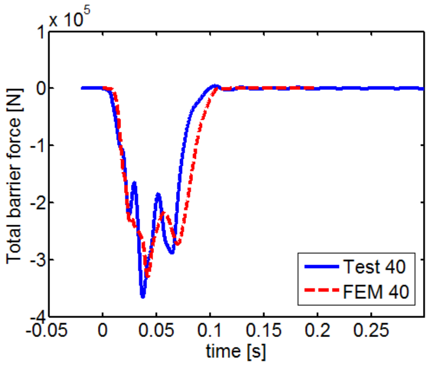
The FEM consists of 4738 beam, 1250424 shell and 258898 solid elements, 1480422 nodes and 917 different parts. There are 4425 beam element connections, 727 nodal rigid body connections, 20 extra node set connections, 4107 spot-weld connections and 39 joint connections. The FEM of the 2010 year model car is depicted in Fig. 11. The contact

modelling of the finite element analysis is handled using automatic single surface and tied shell to surface contacts. The most implemented material model in the FEM is the piecewise linear plasticity. Moreover, elastic, blatz-ko rubber, low density foam and modified piecewise linear plasticity material models are also utilized in the FEM to successfully simulate the dynamic behaviour of the 2010 model year car under frontal impact test. There are five different integration formulas used in the FEM to model the structural behaviours of the finite elements in the model. The Hughes-Liu and Belytschko-Tsay integration formulas are used to simulate the beam elements. The motion of shell elements is employed using very fast fully shell element integration and the behaviour of solid elements is represented by fully accurate S/R solid intended integration formula. In order to decrease the solution time, the time step of the analysis is chosen to be as high as possible without affecting the accuracy of the FEM and mass scaling condition. To simplify the above steps of the FEM model, a brief information on the solution preparation scheme is itemized and outlined below.

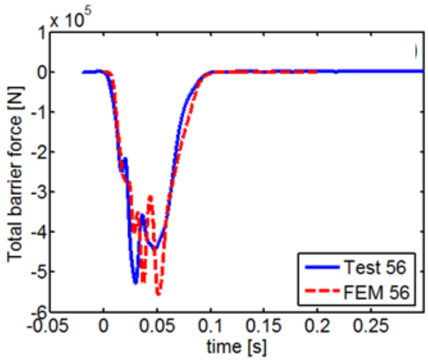
- Input the geometry of the 2010 model year car to LS-Prepost (2018) keyword manager program.
- Mesh the 3D geometry of the 2010 model year car using beam, shell and solid elements.
- Input the constraints and boundary conditions into the model in LS-Prepost (2018) keyword manager program (Cylindrical, revolute, spherical and translational joints, nodal rigid bodies and spot-welds).
- Define the contact between the 2010 model year car and the full-width rigid barrier (FWRB) (Automatic single surface, tied shell edge to surface and interior contacts).
- Input the control parameters of the FEM (Accuracy, CPU, hourglass, energy, termination and time step).
- Input the impact velocity of the 2010 model year car (Initial velocity generation).
- Input the material properties (Elastic, blatz-ko rubber, low density foam, piecewise linear plasticity, modified piecewise linear plasticity, elastic spring, viscous damper, rigid and nonlinear elastic spring).
- Choose the integration formulas to simulate the behaviours of the finite elements (Hughes-Liu, Belytschko-Tsay, very fast fully shell element integration, fully accurate S/R solid intended integration).
- Choose the post processing parameters (ASCII options, binary d3plot, binary d3thdt, binary intfor, history node).
- Solve the FEM using LS-DYNA solver in ANSYS Mechanical APDL Solver (2018) using distributed computing for INTEL MPI.
- Post process the desired results in LS-Prepost (2018) keyword manager program.

4. Validation of the FEM of the 2010 Year Model Car

The FE model of the car is validated against real FWRB crash test data at impact speeds of 40 km/h and 56 km/h. Fig. 4 shows the time variation of total barrier force acting along the x-axis of the global coordinate system; it can be seen that the order of magnitude of the forces, peak timing and the impact duration in the crash test and the FE simulation are similar. Fig. 5 shows the occupant compartment acceleration along the x-axis of the global coordinate system. In the crash test, occupant compartment acceleration is obtained from the accelerometers at the left and right rear seats; in the finite element model (FEM), the accelerations are measured at the same locations. There is a close match in acceleration response between the crash test and the FEM except the sharp peak in the crash test data at 40 km/h.



a

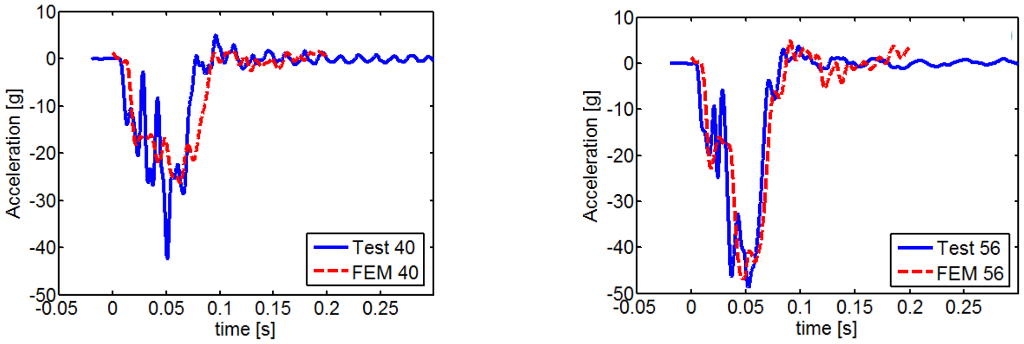


b

Fig. 4 Barrier force variation (2010 year model car): Crash test vs FEM response, (a) 40 km/h, (b) 56 km/h

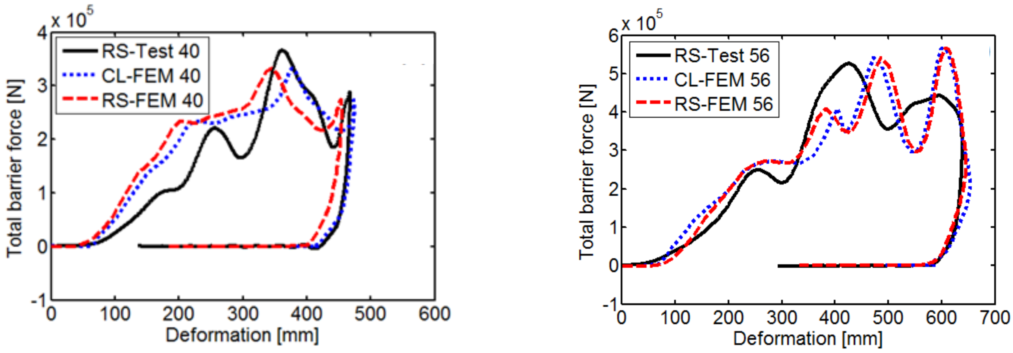
In Fig. 6, the total barrier force is plotted against the deformation of the car. In the crash test, the deformation of the car is estimated from the double integration of the accelerations at the left and right rear seats; in the FE simulation the deformation of the car is estimated in two different ways. As shown in Fig. 6, the curves denoted by RS (rear seat) correspond to the deformation in the FEM which is obtained in the same way as the crash test. In the curves denoted by CL in Fig. 6, the deformation of the car in the FEM is obtained by measuring the change in the length of the car along the longitudinal centreline of the car; for this purpose two nodes are marked at the front and at the rear ends of the car. It can be seen that force versus deformation behaviour in the crash test and the FEM are similar in shape with some acceptable differences in peak values and timing.

The differences between experimental and FEM results occur because the material properties cannot be modelled exactly, some parts of the car are not modelled exactly (e.g. the tyre rubber is modelled as an elastic material and the tyre does not blow out during crash; the hub of the wheels are defined as rigid), furthermore there are different mesh sizes and types for different parts of the car.



a b

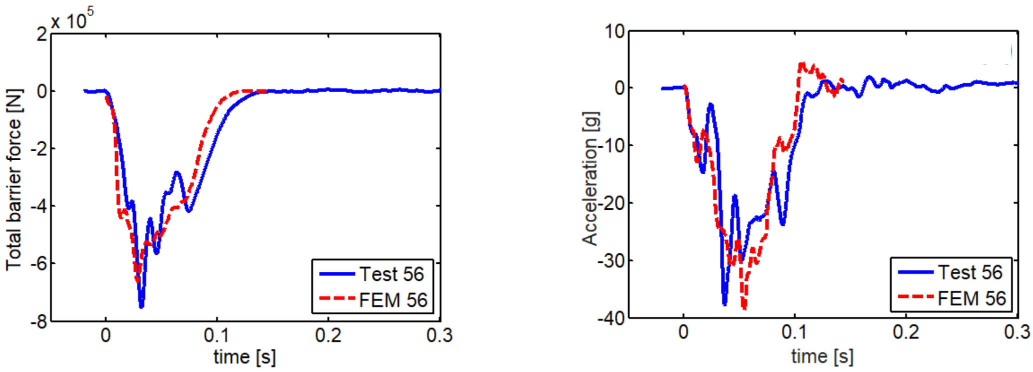
Fig. 5 Occupant compartment acceleration (2010 year model car): Crash test vs FEM (a) 40 km/h, (b) 56 km/h



a b

Fig. 6 Barrier force vs deformation (2010 year model car): Crash test vs FEM response, (a) 40 km/h, (b) 56 km/h

The validation of the FEM was also performed by NCAC [5] but there are some differences between this study and the NCAC report regarding the responses of the FEM. In 40 km/h case, although the acceleration responses are similar in shape, the peak acceleration value in this study is about 4g lower in magnitude. In 40 km/h case, the maximum deformation is about 6 cm more in this study. In 40 km/h case, the peak barrier-force is 15% lower in this study and there is a second peak in force which is lower in magnitude whereas this second peak does not exist in the NCAC report [5]. In 56 km/h case, barrier-force time variations are similar in shape but the timing of peak values are different. In 56 km/h case, barrier force versus deformation curve shapes are a bit different especially at higher deformations and in the NCAC report, the maximum deformation is about 8 cm lower. The NCAC report does not involve barrier force versus the change-in-length of the car as described in this study.



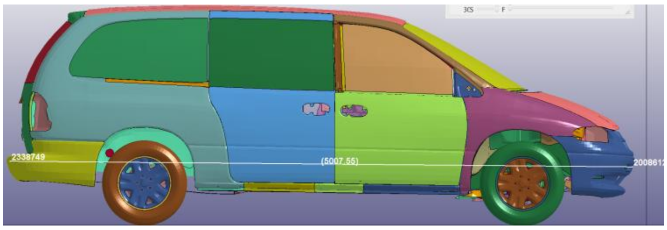
a b

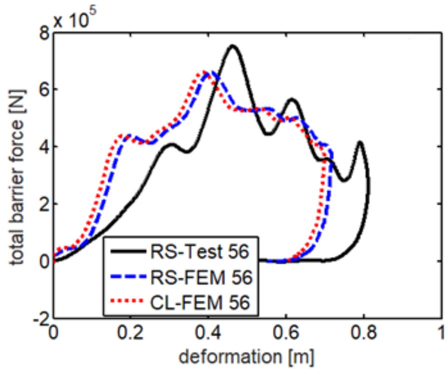
Fig. 7 Crash test vs FEM at 56 km/h (1997 Year Model Van): a - Barrier force; b - Occupant compartment acceleration

5. Validation of the FEM of the 1997 Year Model Van

The FE model of the van is validated against real FWRB crash test data at an impact speed of 56 km/h (as shown in Fig. 7 and Fig. 8) since this is the only crash test data available. It can be seen that barrier force and acceleration responses are similar with some acceptable differences in peak values and timing. However, there are significant differences in the barrier force versus deformation curve as shown in Fig. 8, b where the curves denoted by RS correspond to the deformation in the FEM which is obtained in the same way as the crash test. In the curve denoted by CL, the deformation of the car in the FEM is obtained by measuring the change in the length of the car along the longitudinal centreline of the car as shown in Fig. 8, a. In the FEM, the maximum deformation of the van is about 9.5 cm less than that of the real crash test; this seems to stem from the rubber tyre which behaves too stiff.

The validation of the FEM of the van was also performed by NCAC [6]. In comparison to the NCAC report [6], this study has found similar barrier-force time variation with similar peak timings. The shapes of the acceleration responses in both studies are similar but in this study peak acceleration is 3g higher and the peak timing is 15 ms earlier. Total barrier-force versus deformation curve does not exist in the NCAC report.





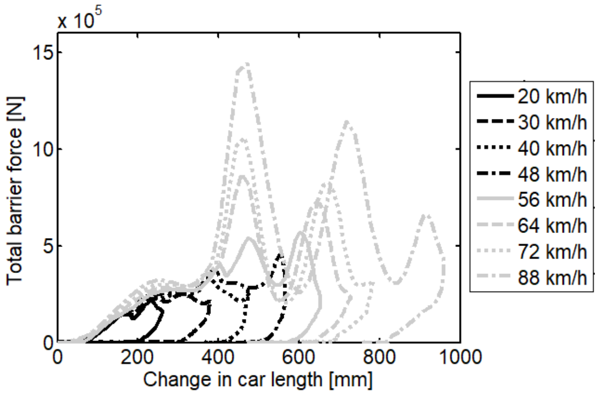
a b

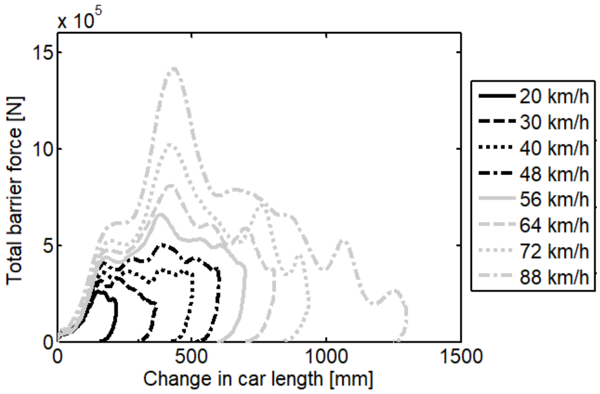
Fig. 8 a - Measurement of change in length (CL); b - Barrier force vs deformation at 56 km/h (1997 Year Model Van)

6. Virtual FWRB Impact Testing

In order to estimate the force-versus-deformation behaviour of the car structure at impact speeds other than 40 km/h and 56 km/h, FWRB impact tests are performed virtually using LS-DYNA finite element program. Fig. 9 shows the total barrier force versus change-in length of the cars for the impact speed range 20-88 km/h. As an example, Fig. 10 shows the FEM of the 2010 year model car just after the impact at impact speeds 20 km/h, 40 km/h, 56 km/h, 72 km/h, 88 km/h and 120 km/h. The occupant compartment of the 2010 year model car deforms significantly for impact speeds higher than 72 km/h.

Fig. 9 indicates that barrier force versus deformation curves at higher speeds encompass the curves at lower speeds. At impact speeds higher than 56 km/h, occupant compartment deformation becomes visible and the strain-rate effects become quite significant which is evident from the higher forces required to deform the car structure by the same amount at higher impact speeds.





a b

Fig. 9 Barrier force vs change-in-car-length: a - 2010 year model car; b - 1997 year model van

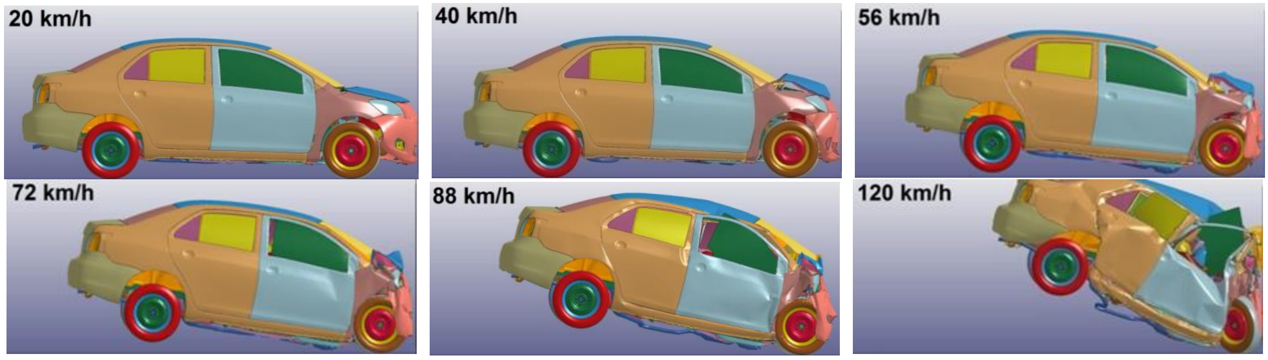


Fig. 10 FEM of the 2010 year model car, just after impact at six different impact speeds

7. Piecewise Linear Approximation of the Barrier Force versus Deformation Curves

In this section, piecewise linear approximation of the barrier (or crush) force versus deformation curves of the 2010 model year car is presented since the FEM responses of this car are closer to the actual responses of the car. Fig. 9(a) indicates that for impact speeds at or below 56 km/h, the deformation behaviour of the car structure is less sensitive to strain rate and it is possible to define a single stiffness value to represent the crush force versus deformation behaviour of the car in the loading phase. The modelling of crush force versus deformation behaviour of the car structure should be performed in a different manner for impact speeds higher than 56 km/h.

Fig. 11 shows a typical crush force versus deformation curve of a passenger car along with its piecewise linear approximation in the simplest way. In this figure, k_L and k_U are the loading and unloading stiffnesses respectively; x_P and x_T are the permanent deformation and total (maximum) deformation respectively; F^* is defined as the separation force. k_L is determined by equating the area under the crush force versus deformation curve in the loading phase to linear-spring energy. US NCAP FWRB crash test data are utilised to determine the parameters k_L, k_U, x_P, x_T and F^*. The unloading stiffness k_U is the slope of the straight line joining the coordinates (x_T, F^*) and $(x_P, 0)$; the area under this straight line is set to be equal to the elastic energy returned by the car structure in the unloading phase and in this way, the separation force F^* is determined. The equations used to calculate the parameters k_L, k_U and F^* can be found in reference [7]. The ratio F_{max}/F^* is defined as the force drop ratio c.

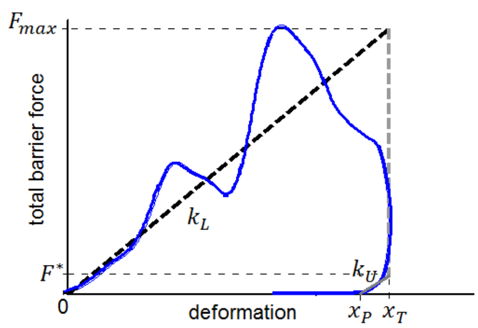


Fig. 11 Linear approximation at 56 km/h

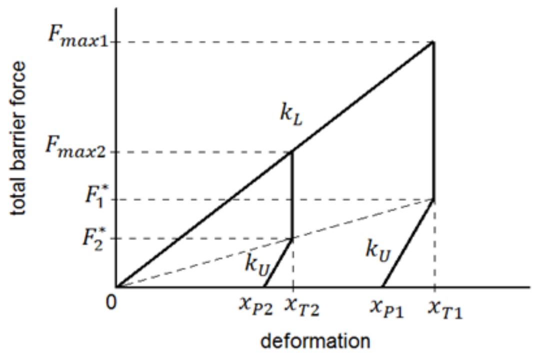


Fig. 12 Linear approximation for different speeds

Once the parameters k_L, k_U and c are determined from the US NCAP FWRB crash test data at an impact speed of 56 km/h, the piecewise linear approximation of crush force versus deformation curves at lower impact speeds can be obtained by using the geometrical approach given in Fig. 12 in which F_{max1} and F_{max2} are the the maximum crush forces developed at impact speeds 1 and 2 respectively; F_1^* and F_2^* are the separation forces at impact speeds 1 and 2 respectively; x_{T1} and x_{T2} are the maximum deformations at impact speeds 1 and 2 respectively; x_{P1} and x_{P2} are the permanent deformations at impact speeds 1 and 2 respectively. For impact speeds 1 and 2, k_L, k_U and c are defined to be the same. Hence, k_L, k_U and c are considered to be the characteristics of the car structure.

The modelling of the crush force versus deformation behaviour of the car structure can be used in a lumped-mass model to simulate FWRB impacts as shown in Fig. 13. The block with mass m in the lumped-mass model of the car is constrained to travel in the x-direction only since this is the predominant motion in FWRB impacts at or below 56 km/h. In the lumped-mass model, the spring like element simulates the crush force versus deformation behaviour of the car structure using piecewise linear approximation as described in Fig. 11 and Fig. 12.

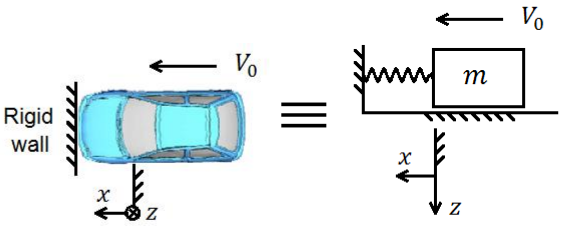


Fig. 13 Lumped-mass model of the car to simulate FWRB impacts

In order to validate the lumped-mass model, FWRB crash test data of the 2010 year model car is used which is given in Section 4. The fixed parameters of the lumped-mass car model are k_L, k_U, c and the mass m, thus the responses of this model at different impact speeds are found by varying only the impact speed in the model. The lumped-mass model aims at predicting the key responses regarding the crash performance of the car. These key responses are x_T (maximum deformation of the car), x_P (permanent deformation of the car), F_{max} (maximum crush-force), F_{mean} (mean crush-force), a_{max} (peak x-acceleration of the occupant compartment), a_{mean} (mean x-acceleration of the occupant compartment), V' (rebound velocity of the car), e (coefficient of restitution of the impact).

For the 2010 year model car, Fig. 14 shows the crush force versus deformation responses of the lumped-mass model and the actual car in FWRB impacts at 40 km/h and 56 km/h. The dashed lines in Fig. 14 correspond to the response of the lumped-mass model. Tables 1 and 2 compare the key responses of the model and the actual car which are in good agreement with each other except the a_{max} value (see Fig. 5, a) at 40 km/h impact speed. Matching a_{max} values is not easy since sharp peaks in acceleration can still reside despite the filtering process. There is only a difference of 3 cm to 4 cm in the values of maximum deformation of the car.

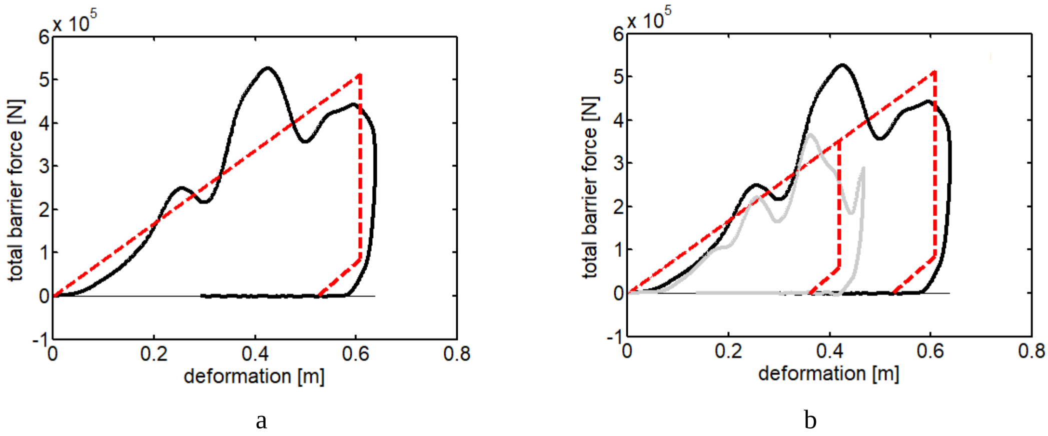


Fig. 14 Crush force vs deformation response: Model vs actual car, (a) 56 km/h, (b) 40 km/h and 56 km/h

Table 1

Model vs actual car responses: FWRB impact at 56 km/h (kph)

	m	x_T	x_P	F_{max}	F_{mean}	a_{max}	a_{mean}	V'	e
Model	1277 kg	0.609 m	0.524 m	513 kN	256 kN	-40.93 g	20.46 g	-8.6 kph	0.152
Actual car	1277 kg	0.639 m	0.55 m	526 kN	269 kN	-48.74 g	21.46 g	-9 kph	0.16

Table 2

Model vs actual car responses: FWRB impact at 40 km/h (kph)

	m	x_T	x_P	F_{max}	F_{mean}	a_{max}	a_{mean}	V'	e
Model	1212 kg	0.420	0.361 m	353 kN	176 kN	-29.70 g	14.85 g	-6.1 kph	0.152
Actual car	1212 kg	0.468 m	0.42 m	366 kN	151 kN	-42.46 g	12.68 g	-6.4 kph	0.161

8. Discussion and Conclusions

Since real crash tests are expensive, mathematical modelling and simulation is required to estimate the crash performance of cars. This study is part of an ongoing project for estimating efficiently the crash performance of cars in 100% overlap single vehicle impacts (such as FWRB impacts) and two-vehicle head-on frontal collisions. The available FWRB crash test data (mostly at 56 km/h and only a few at 40 km/h) and the finite-element simulations of the limited number of car models are the only sources to derive the crush force versus deformation behaviour and the acceleration response of the overall car structure [7-10]. The produced crush-force versus deformation curves are used to derive overall

stiffnesses of the car structure which are useful parameters for vehicle safety design studies (such as road barriers, underride protection devices), accident reconstruction, statistical analysis of cars, and load compatibility analyses [2, 3, 7, 8].

For impact speeds at or below 56 km/h, the piecewise linear approximation of the crush force versus deformation curves produces single values for loading and unloading stiffnesses which can be used to classify cars and obtain analytical solutions to 100% overlap single vehicle impacts and two-vehicle head-on frontal collisions. Defining single stiffness value for the loading phase is suitable for the structures of many cars at impact speeds around or below 56 km/h since the crush forces are less sensitive to deformation rate in this speed range; this observation is supported by the crush force versus deformation behaviours of 10 different cars subjected to FWRB impact tests [7, 9]. For impact speeds higher than 56 km/h in FWRB impacts, the deformation rate effects becomes much more significant and the occupant compartment begins to deform, thus for such higher impact speeds the piecewise linear approximation of the crush force versus deformation curves will be performed differently in another study.

The piecewise linear approximation of the crush force versus deformation curves is used in conjunction with a lumped-mass model to obtain with good accuracy the key responses of the car such as total mean/peak forces acting on the car, mean/peak accelerations of the occupant compartment and the change in the length of the car. The presented lumped-mass modelling approach helps to estimate cheaply the crash performance of cars at impact speeds different than those in the regulatory and consumer crash tests. The presented lumped-mass model of the car has one degree of freedom to simulate FWRB impacts but for impact speeds higher than 56 km/h, the forward pitch of the car (see Fig. 10) must be taken into account to produce a lumped-mass model with higher degrees of freedom and such a model requires the knowledge of the mass centre and inertia of the car.

References

1. National Highway Traffic Safety Administration (NHTSA) [online cit.: 2018-06-03]. Available from: www.nhtsa.gov
2. **Himmetoglu, S.** 2016. An Analysis of Load Incompatibility in Central in-line Collisions of Vehicles Using Lumped-mass Modelling, Proceedings of 17th UMTIK Conference, Bursa, Turkey.
3. **Wiacek, C.; Nagabhushana, V.; Rockwell, T.; Summers, S.; Zhao, L.** 2015. Evaluation of Frontal Crash Stiffness Measures from the U.S. New Car Assessment Program, Proceedings of 24th ESV Conference, Gothenburg, Sweden, paper 15-0257.
4. **Society of Automotive Engineers (SAE)**. 2007. SAE J211-1 (1995): Instrumentation for Impact Test, Part 1, Electronic Instrumentation.
5. **Marzougui, D.; Samaha, R.R.; Cui, C.; Kan, C.-D.** 2012. Working Paper NCAC 2012-W-005. National Crash Analysis Center (NCAC), The George Washington University.
6. **Marzougui, D.; Mohan, P.; Kan, S.; Nagabhushana, V.** caravan-V07-readme.pdf. National Crash Analysis Center (NCAC), The George Washington University. Available from: www.nhtsa.gov
7. **Himmetoglu, S.** 2018. Derivation of Stiffnesses for Comparison of Vehicle Performance in Frontal Impacts, Proceedings of 18th UMTIK Conference, Eskişehir, Turkey.
8. **Galipeau-Bélair, P.; El-Gindy, M.; Ghantae, S.; Critchley, D.; Ramachandra, S.** 2014. Development of a regulation for testing the effectiveness of a rigid side underride protection device (SUPD), International Journal of Crashworthiness 19(1): 89-103.
9. **Tolman, S.S.** 2008. Analysis of Load Cell Barrier Data for Accident Reconstruction Applications. MSc Thesis, The University of Utah.
10. **Wei, Z.** 2017. Analysis, Modeling and CAE Validation of Vehicle Crashes using Advanced Signal Processing Tools. PhD Thesis, University of Agder.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Methods for Safety Assessment of Unprotected Road Traffic Users

M. Dębowska-Mróz[1], E. Ferensztajn-Galardos[2], R. Krajewska[3], A. Rogowski[4]

[1]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: m.mroz@uthrad.pl*
[2]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: e.ferensztajn@uthrad.pl*
[3]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: r.krajewska@uthrad.pl*
[1]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: a.rogowski@uthrad.pl*

Abstract

Road traffic safety is an important element of the assessment of the transport system operation. Especially in cities, the assessment of the safety of unprotected road users is a significant problem. An important step in this assessment is to identify places where accidents involving pedestrians and places of occurrence that may be the cause of their occurrence. The article presents the methods of identifying such places, including the author's method of identifying places of occurrence of threats involving pedestrians in medium-sized cities.
KEY WORDS: *road safety, unprotected participant of road traffic, safety measures, analysis of traffic threats*

1. Introduction

Road traffic safety is a problem concerning the functioning of road transport around the world. Every year, about 1.3 million people lose their lives in road accidents and a further over 20 million people suffer various injuries, often affecting their health and functioning. There are 8-9 deaths per 100 road accidents in Poland. Meanwhile, this number is about 2-4 victims per 100 accidents in Western European countries.

Road traffic safety is a problem that is solved by numerous teams of scientists representing various scientific disciplines and responsible entities, such as: for functioning, operation and supervision of the functioning of road transport. First of all, the main problems and groups of traffic risks should be identified in order to effectively prevent road accidents, reduce the number of victims, minimize economic and social costs. Based on the acquired knowledge, appropriate actions can be taken and implemented to improve the existing situation in the field of road safety.

2. The Importance of Road Traffic Safety

In recent years, research on road traffic safety has been one of the most important and dynamically developing fields of science. This is a very complex field that requires a systemic and interdisciplinary approach. The essence of road safety is the conflict-free participation in road traffic of all its participants [1, 2]. The aim of road traffic safety research is to analyze the HUMAN-VEHICLE-WAY SYSTEM (and its environment), identify possible measures to improve it and assess the effects of these measures. Main goals of security research can be formulated [4]:

– identification of mechanisms of threat creation;
– building defense mechanisms appropriate to specific threats;
– testing intentional risk (risk assessment).

Traffic accident statistics are the basic source of information on traffic incidents. It should be remembered that [6]:

– traffic accidents are relatively rare events;
– traffic accidents provide ex post information, which is tantamount to traffic victims;
– the number of accidents at a particular place is usually small;
– these accidents occur at a certain time (sometimes large), which due to the change of traffic conditions are not comparable;
– these data are not sufficiently accurate (inaccurately completed "accident cards"), the information obtained in this way allows to consider the event in terms of guilt and not the causes of accidents.

The most important advantage of this source of information is that thanks to the obtained statistics, it is possible to track general trends and directions of development of accident situations.

3. Types of Statistical Analyzes of Road Traffic Safety

Assessment and analysis of road safety on the basis of statistical data are carried out in many directions and at different levels of detail. Multi-directional nature results from the variety of factors affecting road safety and the diver-

sity of remedial actions taken.

In road traffic safety studies, the most frequently paid attention is to the systematics and the quantitative description of the state of road traffic safety. This can be done using: statistical statements, statistical indicators, regression relationships, operative safety indicators. The safety assessment can be a global, general or specific assessment. Global assessment is a country-focused assessment, the purpose of which is to present selected measures and indicators characterizing road safety in a given country and to compare these values with data in other countries (Table 1).

Table 1

Summary of the number of fatal victims in selected EU countries in 2001, 2010 to 2016

Country	Year								Change dynamics %	
	2001	2010	2011	2012	2013	2014	2015	2016	2010-2015	2014-2015
Austria	958	552	523	531	455	430	479	-	-13%	11%
Belgium	1486	841	861	767	720	727	732	-	-13%	1%
Croatia	647	426	418	393	368	308	348	-	-18%	13%
Czech Republic	1334	802	773	742	650	685	738	610	-8%	8%
Denmark	431	255	220	167	192	182	179	215	-30%	-2%
France	8162	3992	3963	3653	3250	3384	2461	3469	-38%	-27%
Greece	1880	1258	1141	984	870	795	798	807	-37%	0%
Spain	5517	2478	2060	1903	1680	1688	1689	-	-32%	0%
Ireland	411	212	186	162	190	193	162	-	-24%	-16%
Lithuania	706	299	296	302	256	267	242	188	-19%	-9%
Luxembourg	70	32	33	34	45	35	36	32	13%	3%
Latvia	558	218	179	177	179	212	188	157	-14%	-11%
Malta	16	15	17	9	18	11	10	22	-33%	-9%
Netherlands	1083	640	661	650	570	570	621	-	-3%	9%
Germany	6977	3651	4009	3601	3340	3377	3459	3206	-5%	2%
Norway	275	210	168	145	190	147	117	135	-44%	-20%
Poland	5534	3907	4189	3571	3357	3202	2933	2992	-25%	-8%
Portugal	167	937	891	743	650	638	593	-	-37%	-7%
Romania	2461	2377	2018	2042	1861	1818	1893	-	-20%	4%
Slovakia	625	353	324	295	223	295	310	-	-12%	5%
Slovenia	278	138	141	130	125	108	120	131	-13%	11%
Switzerland	544	327	320	339	269	243	253	216	-23%	4%
Sweden	534	266	319	285	260	270	259	216	-3%	-4%
Hungary	1239	740	638	605	591	626	647	607	-13%	3%
Italy	7096	4114	3860	3653	3400	3381	3428	-	-17%	1%
Great Britain	3598	1905	1960	1802	1790	1775	173	-	-9%	-3%

Source: own study based on [1]

The measures and indicators chosen for the analysis are related to different time horizons (monthly, quarterly, and annual). They are cyclical evaluations. They are given, for example, absolute values taking into account the number of accidents and collisions, killed and injured (Table 2).

Table 2

Summary data on the number and consequences of road accidents taking into account the safety of unprotected road users in Poland in 2006-2017

Year	Total			Pedestrian			Cyclists			Moped drivers			Motocyclists		
	Accidents	Killed	Injured	Accidents	Killed	Injured	Accidents	Killed	Injured	Accidents	Killed	Injured	Accidents	Killed	Injured
2008	49054	5437	62097	15024	1882	13912	5150	433	4494	2728	87	2222	2880	262	2270
2009	44196	4572	56046	12834	1467	12025	4513	371	3926	2294	68	2223	2576	290	2297
2010	38832	3907	48952	11286	1236	10580	3918	280	3494	1871	83	1886	2392	259	2161
2011	40065	4189	49501	11220	1408	10319	4652	313	4118	1929	87	2176	2359	292	2439
2012	37046	3571	45792	10309	1157	9694	4665	300	4135	2036	82	1989	2395	261	2186
2013	35847	3357	44059	9489	1140	8802	4723	304	4144	1972	62	1921	2210	253	2075
2014	34970	3202	42545	9106	1116	8398	4850	286	4270	1950	71	1866	2378	237	2233
2015	32967	2938	39778	8581	923	8188	4634	303	4473	1727	65	1657	2136	225	2188
2016	33664	3026	40766	8461	868	7974	4737	271	4298	1522	77	1283	2299	244	2067
2017	32760	2831	39466	8197	873	7587	4212	220	3824	1334	55	1276	2240	231	2032

Source: own study based on [12]

Pedestrians are the largest group of road accident victims from unprotected road users: about 50% of all victims

and almost twice as many fatalities as cyclists, moped drivers and motorcyclists together. Simultaneously, they constitute about one third of all fatalities and about 24% of all road accident victims in Poland [12].

There are also determined measures and indicators being a reference to selected specific features that enable road traffic safety characteristics. A comparison of data on road accidents for selected groups of road users is often made in order to determine the specificity of the number of these events (see Chapter 4). Based on available statistical data, basic statistical parameters can be determined: mean, standard deviation, median and coefficient of variation, linear correlation coefficient, etc.

4. Statistical Data as an Element of Traffic Safety Forecasts

In the literature [10] studied the possibility of using classical models trend as univariate models for modeling the number of victims unprotected road users in road accidents in Poland. As independent variables were considered general: the number of accidents, number of deaths, the number of wounded and the total number of victims. Four categories of unprotected road users were distinguished: pedestrians, cyclists, moped drivers and motorcyclists. One-equation and two-equation models (bonding functions) were used, as a different character of changes was noted for large values of the explanatory variable and another for small values. The R2 coefficient of determination was used as a measure of matching. Linear models were also given. An important result was that for pedestrians and cyclists the number of victims (in all three categories) is a function of the growing explanatory variables (all), and in the case of moped drivers and motorcyclists, a decreasing function. In the case of pedestrians of road users and the number of fatalities among cyclists, an unexpectedly good fit of all models for all modeled variables was found. In other cases, the match is at most good and in the case of the number of fatalities among moped drivers very poor. This puts into question the usefulness of these models for forecasting. After three years, the accuracy of forecasts using these models was verified. (Tables 3 and 4 give only models for which the forecasts were at least acceptable).

Table 3

Actual number of victims of unprotected traffic participants in Poland in 2015-2017 and values obtained from selected one- and two-equation univariate models given in [10]

No.	**Explanation variable *y***	***x***	**Equation**	**2015**			**2016**			**2017**		
				WR	**WM**	**B [%]**	**WR**	**WM**	**B [%]**	**WR**	**WM**	**B [%]**
one-equation models												
1	pedestrians injured	1	$y=\frac{x}{6{,}946193-0{,}000045x}$	8040	7715	-4.2	7974	7975	0.0	7587	7633	0.6
2		3	$y=\frac{x}{6{,}019479-0{,}000045x}$	8040	7268	-10.6	7268	7473	-6.7	7587	7207	-5.3
3	total number of victims	1	$y=\frac{x}{5{,}283405-0{,}00004791702x}$	8963	9561	6.3	8842	9874	10.5	8460	9469	10.7
two-equation models												
4	pedestrians killed	2	$y=\frac{1}{0{,}001461-0{,}0000001722735x}$	923	909	-1.6	868	918	5.4	873	898	2.8
5	pedestrians injured	1	$y=0{,}000415\,x^{1{,}609749}$	8040	7781	-3.3	7974	8047	0.9	7587	7702	1.5
6		4	$y=\frac{x}{7{,}061601-0{,}000036568882x}$	8040	7767	-3.5	7974	8020	0.6	7587	7670	1.1
7	pedestrians, the total number of victims	1	$y=0{,}000499x^{1{,}603685}$	8963	8784	-2.0	8842	9083	2.7	8460	8695	2.7
8		4	$y=\frac{x}{6{,}216823-0{,}0000314965439374x}$	8963	8769	-2.2	8842	9053	2.3	8460	8659	2.3
9	cyclists injured	1	$y=0{,}065496x+1606$	4111	3765	-9.2	4298	3811	-12.8	3824	3752	-1.9
10	cyclists total number of victims	1	$y=0{,}081708x+1300$	4414	3994	-10.5	4569	4051	-12.8	4044	3977	-1.7

Models developed on the basis of statistical data from 2001-2013. For two-equation models, only the equation corresponding to the range of variables from 2014-2017 is given.

WR - actual value; WM - value of the model; B - relative error (specifies how many percent should be corrected WM to obtain WR, minus sign means undervaluation); x - explanatory variable: 1 - total number of accidents, 2 - total number of fatalities, 3 - total number of injured, 4 - total number of victims (injured + killed)

Only model 1 from the one-equation models (Table 3) "predicted" the value of the number of injured pedestrians sufficiently accurately. Models 2, 3 (the number of pedestrians injured and victims) and 4 (the number of deaths - motorcyclists) can be considered acceptable. In the case of two-equation models (Table 3), all models distinguished provide very good or good estimates for pedestrians of road traffic participants and allowable for the number of injured and the total number of victims for cyclists (Table 3). The other models are unfortunately not useful in forecasting (although some of them showed a very good fit for the data on the basis of which the parameters were estimated). In the case of linear models only the models of the total number of pedestrian victims (for all explanatory variables), the number of fatalities as a function of the total number of fatalities and the number of injured motorcyclists as a function of the total number of accidents give acceptable values (Table 4). These results could be expected by analyzing the diagrams in [10] - the trend lines clearly bent at the ends of the variability areas of the explanatory variables.

One of the most important problems to solve is the randomness of the analyzed phenomena [4]. The examination of randomness or setting trends in the time of accidents and accident victims of distinguished groups of road traffic participants to the total number of accidents and victims can be interpreted as an explanatory variable, in which the models did not state directly the number of accidents and accident victims. It was decided to analyze the data on an annual and three-year basis. Randomness was found in the case of the participation of pedestrians in fatalities (i.e., participation is a constant "disturbed" random factor). This situation also occurred in the case of fatalities of motorcyclists among the total victims. This applies to both the annual and three-year analyzes. The occurrence of a trend or discrepancy between the analysis on an annual and three-year basis was found in the majority of the remaining cases. Statistical analysis of the data showed that the separation of the group of "unprotected road users" for which the criterion of "lack of passive means of protection" is inappropriate not only because of the different rights of individual road users. Only the groups "moped drivers" and "motorcyclists" have common characteristics, but in this case there is a significant difference in the "severity" of accidents.

Table 4

Estimation of the number of victims of unprotected traffic users in Poland in 2015-2017 by means of linear models given in [10]

x	Year	**killed**				**injured**				**victims**			
		equation	***y* [%]**	**WR [%]**	**B [p.p.]**	**equation**	**WM [%]**	**WR [%]**	**B [p.p.]**	**equation**	**WM [%]**	**WR [%]**	**B [p.p.]**
		pedestrians											
15	2015	$y = -0.0003x + 0.3383$	33.38	31.42	1.96	$y = -0.0055x + 0.2719$	18.94	20.21	-1.27	$y = -0.0052x + 0.2776$	19.96	20.98	-1.02
16	2016		33.35	28.68	4.67		18.39	19.56	-1.17		19.44	20.19	-0.75
17	2017		33.32	30.84	2.48		17.84	19.22	-1.38		18.92	20.00	-1.08
		cyclists											
15	2015	$y = -0.0039x + 0.1194$	6.09	10.31	-4.22	$y = -0.0013x + 0.0942$	7.47	10.33	-2.86	$y = -0.0015x + 0.0962$	7.37	10.33	-2.96
16	2016		5.70	8.96	-3.26		7.34	10.54	-3.20		7.22	5.28	1.94
17	2017		5.31	7.77	-2.46		7.21	9.69	-2.48		7.07	5.35	1.72
		moped drivers											
15	2015	$y = 0.0011x + 0.0064$	2.29	2.21	0.08	$y = 0.0029x + 0.0059$	4.94	4.17	0.77	$y = 0.0031x + 0.006$	5.25	4.03	1.22
16	2016		2.40	2.54	-0.14		5.23	3.60	1.63		5.56	3.53	2.03
17	2017		2.51	1.94	0.57		5.52	3.23	2.29		5.87	3.15	2.72
		motocyclists											
15	2015	$y = 0.0046x + 0.0144$	8.34	7.66	0.68	$y = 0.0029x + 0.0139$	5.74	5.50	0.24	$y = 0.0027x + 0.0138$	5.43	5.65	-0.22
16	2016		8.80	8.06	0.74		6.03	5.07	0.96		5.70	5.28	0.42
17	2017		9.26	8.16	1.10		6.32	5.15	1.17		5.97	5.35	0.62
	three-year perspective												
		pedestrians											
15	2013-2015	$y = -0.0008x + 0.3407$	32.87	33.47	-0.60	$y = -0.0056x + 0.2719$	18.79	19.97	-1.18	$y = -0.0053x + 0.2662$	18.67	20.91	-2.24
16	2014-2016		32.79	31.72	1.07		18.23	19.83	-1.60		18.14	20.66	-2.52
17	2015-2017		32.71	30.29	2.42		17.67	19.67	-2.00		17.61	20.39	-2.78
		cyclists											
15	2013-2015	$y = -0.0031x + 0.1184$	7.19	9.40	-2.21	$y = -0.0009x + 0.0942$	8.07	9.91	-1.84	$y = -0.0007x + 0.0948$	9.48	9.87	-0.39
16	2014-2016		6.88	9.38	-2.50		7.98	10.30	-2.32		9.48	10.24	-0.76
17	2015-2017		6.57	9.03	-2.46		7.89	10.19	-2.30		9.48	10.11	-0.63
		moped drivers											
15	2013-2015	$y = 0.0013x + 0.0061$	2.56	2.08	0.48	$y = 0.0034x + 0.0059$	5.69	4.31	1.38	$y = 0.0032x + 0.0071$	5.51	4.78	0.73
16	2014-2016		2.69	2.32	0.37		6.03	4.05	1.98		5.83	4.91	0.92
17	2015-2017		2.82	2.24	0.58		6.37	3.67	2.70		6.15	4.88	1.27
		motocyclists											
15	2013-2015	$y = 0.0051x + 0.0151$	9.16	7.53	1.63	$y = 0.003x + 0.0139$	5.89	5.14	0.75	$y = 0.0032x + 0.0144$	6.24	5.31	0.93
16	2014-2016		9.67	7.70	1.97		6.19	5.27	0.92		6.56	5.44	1.12
17	2015-2017		10.18	7.96	2.22		6.49	5.24	1.25		6.88	5.42	1.46

x - explanatory variable, another value in the time series; *y* - explained variable, the value obtained from the trend model; B - error of estimation in percentage points

Linear trend models are also given in [4]. The forecasts for 2015-2017 were made by checking their suitability using these models (Table 6). In the one-year system, very good or good forecasts were obtained for the number of pedestrians and motorcyclists and the number of deaths among moped drivers. In the case of analysis in three-year periods in the case of pedestrians and the number of victims of cyclists. Although the absolute error expressed in percentage points is small, it cannot be the only measure. Please refer to the size of the base share. Thereby, for example, forecasts of the share of motorists among fatalities should be considered unhelpful, even though the error did not exceed 0.6 percentage points.

The analysis shows that the most useful (in the sense of the accuracy of the forecast) are those for pedestrians in traffic. Given that the models used are relatively simple, one can claim that the behavior of pedestrians (drivers in relation to pedestrians) is stable in road traffic. However, it is difficult to assess this phenomenon as beneficial. Trends should be considered unfavorable for other groups. The models describing the share give better accuracy of forecasts, however, they are burdened with a significant disadvantage - the explanatory variable is time, so the models do not explicitly state the number of accidents and accident victims.

5. Selected Indicators Used in Assessing the State of Road Traffic Safety [11]

Based on the available statistical data on the events of their effects, it is possible to determine the indicators used to assess the state of road safety may concern whole areas (macro indicators) as well as selected elements of the road network (micro indicators). The choice of indicators used depends on the purpose of the analysis. Macro indicators are used in global analyzes, and micro indicators in general analyzes - including identification of dangerous places. The choice of types of indicators for analyzes depends on their purpose.
The most commonly used macro indicators can include:

– number of accidents per 1 million vehicles *Wp*, i.e .:

$$W_P = \frac{W \cdot 10^6}{P} \text{ [accidents/million vehicles]}, \quad (1)$$

here *W* – total number of accidents in the analyzed time interval; *P* – number of registered vehicles;

– number of accidents per 1 million inhabitants WM, i.e.:

$$W_M = \frac{W \cdot 10^6}{M} \text{ [accidents/million inhabitants]}, \quad (2)$$

here *M* – number of inhabitants.

Other indicators are also calculated in a similar way:

– number of killed, injured for 1 million vehicles or 10 thousand. vehicles;
– number of killed, injured per 1 million inhabitants;
– number of killed, injured on 1 million passenger cars;
– number of accidents (accidents with victims), killed or injured and 1 million vehicles km;
– number of fatalities per 100 injured (accident severity index).

The most commonly used micro indicators on road sections include:

– accident density factor Dw, as the number of accidents per 1 km of road:

$$D_W = \frac{\sum W}{\sum L_i} \text{ [accidents/km]}, \quad (3)$$

here $\sum L_i$ – total length of roads in the network; a given class, a given type, the length of a given road [km];

– relative accident rate U_W, for a given road expressing the number of accidents related to the number of kilometers traveled by vehicles during this time:

–

$$U_W = \frac{\sum_{i=1}^{n} W_i \cdot 10^6}{T \cdot 365 \cdot \sum_{i=1}^{n} Q_{oi} L_i} \text{ [accidents/million vehicles km]}, \quad (4)$$

here Q_{oi} – average daily traffic volume in the year [P/day]; *T* – the period of analysis for which accident data is given in years; W_i – the number of accidents on homogeneous sections of length L_i and intensity Q_{oi}.

Point analysis for safety for intersections, pedestrian crossings and very short sections of roads is performed based on index U_W:

$$U_W = \frac{W \cdot 10^6}{T \cdot 365 \cdot Q_o} \text{ [accidents./million vehicles].} \tag{5}$$

The number of accidents at the intersection depends to a large extent on the intensity distribution at subordinate inlets and on the main road. For this reason, it is advisable to use an indicator taking into account the geometric mean of inflows in the main road Q_g and subordinated to Q_p, i.e. substitution (6):

$$Q_o = \sqrt{Q_g \cdot Q_p}\ . \tag{6}$$

An objective measure of safety status can be considered as the hazard indicator W_z, which is the geometric mean of D_W and U_W indicators, and thus:

$$W_Z = \sqrt{D_W \cdot U_W}\ . \tag{7}$$

Identification of dangerous interstitial sections is performed based on the number of deaths per 100 injured. Such behavior results from the fact that D_W and U_W indicators do not take into account the severity of accidents. One of the ways of its inclusion is the use of weights for individual categories of accidents and including them in the formulas given to D_W, U_W and W_Z, in the form of the so-called the equivalent number of We accidents, bringing different effects of accidents to one reference level:

$$W_o = \sum W_i \cdot g_i\ , \tag{8}$$

here W_i – number of accidents per category (with killed, injured, only with material losses); G_i - accident weights.

Another option to include accident categories is to calculate accident costs, distinguishing their costs. The following indicators can then be used:

– accident cost indicator K_p, defining the costs of accidents as follows:

$$K_o = \frac{\sum W_i \cdot K_i \cdot 10^3}{Q_o} \text{ [PLN/thousand vehicles],} \tag{9}$$

here W_i – number of accidents category i, i = 1, n (n- number of distinguished accident categories); K_i – average cost of the accident for the category i [PLN];

– average cost of the K_w accident, defining the cost of one accident, taking into account the accidents category, i.e .:

$$K_w = \frac{\sum W_i \cdot K_i}{10^3 \cdot W} \text{ [thousand PLN/accidents],} \tag{10}$$

here $W = \sum W_i$.

As representative for the safety assessment for the analyzed area (housing estate, district, city, commune), the area index W_o is determined based on the dependence 11.

$$W_o = \frac{SW_{ZD} \cdot 10^6}{365 \cdot L_s}, \tag{11}$$

here L_s – number of registered motor vehicles in the analyzed area in the year of analysis; SW_{ZD} – weighted sum: accidents, injured and killed.

In the case of traffic safety analyzes at pedestrian crossings it is convenient to use the indicator:

$$Uw = \frac{W \cdot 10^6}{Q_o \cdot \sqrt[4]{Q^p}}, \tag{12}$$

here Q_o – average hourly traffic intensity during the observation period [P/h]; Q_p – average pedestrian traffic during the observation period [PS/h]; W – number of pedestrian accidents.

The abovementioned indicators are based on numerical combinations of the number of accidents and their consequences in relation to already existing events. Therefore, they are, already numerous human tragedies.

6. Safety Assessment Based on Pre-Conflict Events

Road traffic safety can be considered from many points of view and can cover many aspects. There are three levels of traffic situations in road traffic closely related to traffic safety:

– pre-conflict behavior of road users,
– traffic conflicts,
– traffic incidents (accidents and collisions).

To identify a threat at the stage of pre-conflict states, it is necessary to identify potential sources of danger. This can be done on the basis of the analysis of symptoms of threat [3, 7, 11], which can be behavioral indicators of latent threat in road traffic. They can be classified as follows:

– potential dangerous mistakes of road users; that is wrong decisions of individual road users, as well as errors in the behavior on the road conditioning the safe behavior of individual participants,

– spatial (temporary) gaps between vehicles accepted by individual road users; ie the problem of perceiving, assessing and accepting risk in road traffic,

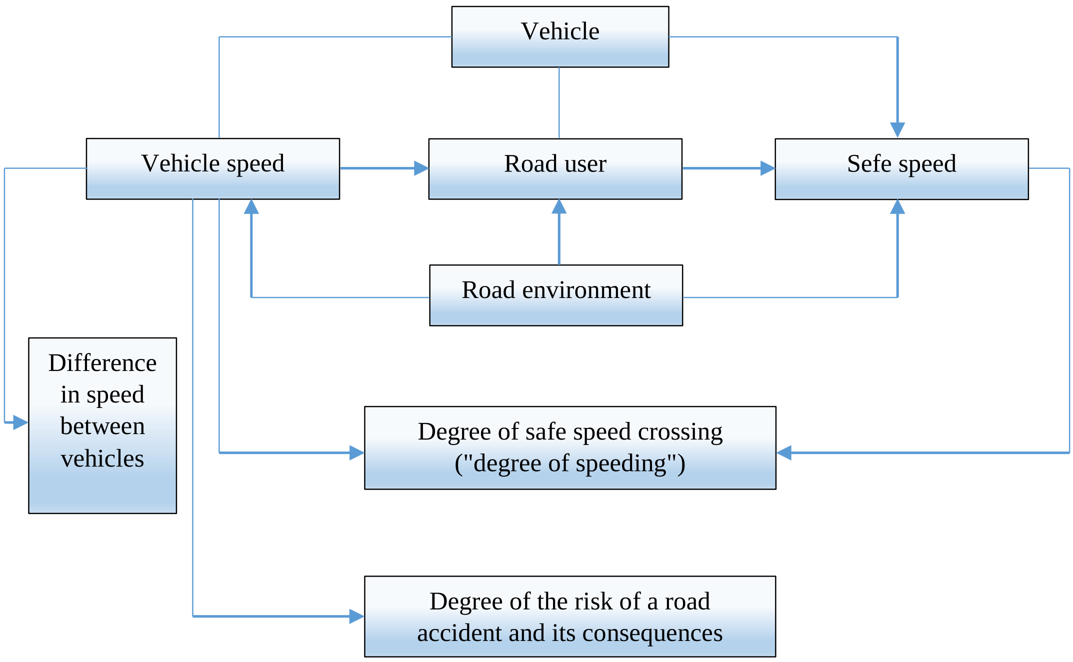
– quantities describing the impact of parameters characterizing traffic and road conditions; e.g. " disruption of acceleration" and "medium speed gradients"; these measures are helpful in developing operative diagnoses of road safety, in particular urban traffic.

– psychophysiological parameters of the road traffic participant, thanks to which one can indirectly conclude about the possibility of dangerous behavior in road traffic.

It is proposed to use the method determining threat symptoms based on behavioral hazard indicators in order to identify the risk of pedestrian safety in road traffic in cities. Indicators using the "disruption of acceleration" level assessment based on the analysis of the speed distribution in relation to selected elements of the road infrastructure. This approach to the analysis of pedestrian safety in road traffic makes it possible to identify potentially dangerous places due to the risk of accidents involving pedestrians.

7. "Disruption of Acceleration" as a Measure of Danger

The speed of vehicles in road traffic can be considered in many respects: from the point of view of the observer and the manager, the legislator and the enforcer of the provisions, or the injured [6]. Speed is also a determinant of the quality of traffic and its consequences in relation to its individual participants (Fig. 1). Decides about comfort, convenience, economy and road safety. Knowledge of the distribution of speed and intensity of road traffic creates the possibility of effective implementation of instruments to improve road traffic safety, planning the development of the road network and coordination of modernization and renovation works.



Source: [2]

Fig. 1 The impact of speed on the degree of risk of occurrence of an incident in road traffic

Accidents occur mainly in the situation of differences in the speed of travel and the directions of movement of road users, while the severity of accidents is determined by the speed of the vehicle and its differences between individual road users.

"Disruption of acceleration" was used to identify accidental places with the participation of pedestrians in Radom. Based on accident data from 1999 and 2011, coming from road accidents records obtained from the Road Traffic Department of the Municipal Headquarters in Radom, particularly dangerous sections of streets in Radom were selected. To assess the risk of accidents with pedestrians, sections of streets with comparable traffic conditions, development of the surroundings and geometrical parameters as well as various accident rates were selected. An analysis of the time distribution of these events was made for these sections. Then, in the time intervals corresponding to the data obtained from the card analysis, the communication paths on which the speed measurements were made were selected. The measurements were made using "the floating-car method". The speed was measured at one-second intervals. Obtained results of speed measurements were transferred to the road profile.

Due to the variety of causes that pose a threat to road traffic, and in urban areas at the same time as their occurrence, it is advisable in the hazard level tests to perform an analysis of the average speed distribution and vehicle speed distribution around the average value. The size of the spread in the conditions of non-urban roads is a measure of the frequency of accidents especially related to overtaking and hitting the vehicle on the vehicle and other road users. In urban conditions, especially on double-axle, bi-directional streets with short inter-node sections, the increase of the speed distribution around the average value can be a measure of the number of disturbances in the flow of a vehicle stream. Disturbances resulting from lateral movement, inability to recognize traffic conditions and selection of appropriate speed, in particular adapted to the visibility of the road and other road users, as well as divergent perception of the rules of functioning of a given road section. Accelerations were calculated on the basis of the determined velocity measurements, which, similarly to the velocities, were presented in relation to the road profile (Figures 2 and 3). Using the rolling averages method, the "disruption of acceleration" σ_a of the vehicle (vehicles) (D.R. Drury) was calculated as a function of the road, which is the mean square deviation of accelerations from the average acceleration of the vehicle (vehicles) involved in the traffic. Based on the "floating-car" model, "disruption of acceleration" can be determined from the relationship represented by the formula (13).

$$\sigma_a = \sqrt{\frac{1}{T}\int_0^T \left[a(t) - \bar{a}\right]^2 dt}\ , \tag{13}$$

here $a(t)$ – acceleration as a function of time; $\bar{a}$ – average acceleration of the test vehicle in the time interval T.

The "disruption of accelerations" was counted on the basis of seven successive acceleration values - the length of the time series was determined empirically (Fig. 2).

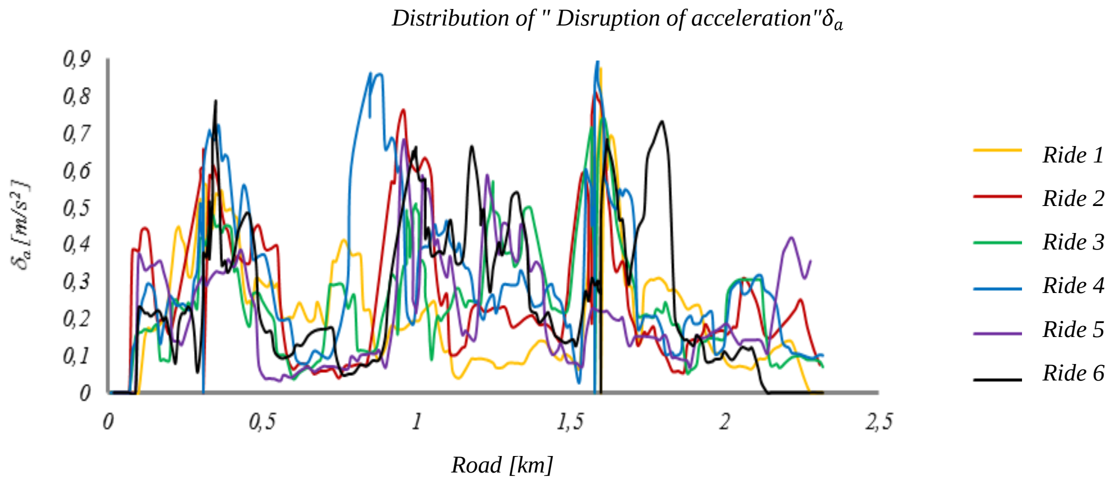


Fig. 2 Distribution of "disruption of acceleration" on one of the sections (Chrobry Street in Radom)

For the data received in this way ("disruption of acceleration"), the quantile 0.8 (80 percentile) and "rolling statistics" from "disruption of acceleration" and the absolute value "disruption of acceleration" were calculated (quantile 0.8 from the set of 10 consecutive values of "disruption of acceleration")). Obtained results (as a function of the road) were marked on one coordinate system with marked locations of occurrence of accidents (Fig. 3).

It can be noticed that the values of rolling statistics are not less than the quantile value of 0.8 "disruption of acceleration" for all speed measurements and all highlighted places that cause accidents. This is a characteristic feature of accidental places on interstitial sections. Such changes can also be observed in the vicinity of intersections with traffic lights in the case when during speeding a speed correction had to be made due to the displayed light signals (Fig. 3).

It is possible to indicate dangerous places from the point of view of pedestrians in road traffic in cities on the basis of statistical analysis of the distribution of "disruption of acceleration". Thanks to this approach to the identification of accidental places with pedestrians, it can indicate in the city's transport system sections for which a detailed assessment of traffic and road conditions should be made, which may be the cause of emerging dangerous events for individual road users.

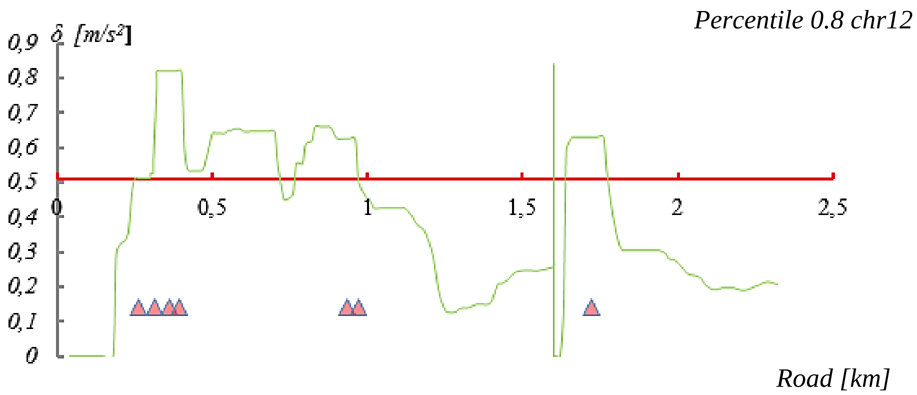


Fig. 3 List of analyzed percentiles of "disruption of acceleration" (Chrobry Street in Radom, direction 1-2)

8. Conclusions

Radical improvement of road safety requires many interdisciplinary activities. They should focus on various problems ranging from the modernization of the existing and construction of new roads and streets, and adaptation to the growing volume of road traffic through activities related to the analysis of the behavior of various road users. They should also cover issues related to vehicles using different road infrastructure. An important task is also the ability to identify dangerous places in road traffic based on ex ante methods. The basic feature of such methods is the use of information on pre-conflict events in road traffic. Undoubtedly, the example of analysis presented above for one of the sections of the communication system in Radom is a proposal for such an approach to the problem of identifying accidental places in cities. Such analyzes may be carried out for infrastructure elements from years in operation, for which there is a need to indicate sections that should be modernized in the first place. It is also possible to carry out such an analysis for new, redesigned elements of the communication system and on the basis of which the places (sections) should be indicated, where detailed traffic and road analyzes should be performed. Only such knowledge will enable conducting appropriate actions aiming at elimination of factors affecting safety and quick response to threats occurring in the road transport system in cities.

References

1. **Anh, T.T., Dao, N.X.** 2005. Conflict technique applied to traffic safety on the model corridor of Ha Noi, Proceedings of the Eastern Asia Society for Transportation Studies, 5: 1875-1890.
2. **Dębowska-Mróz M, Rogowski, A.** 2013. Szum przyspieszenia jako miara bezpieczeństwa pieszych w ruchu drogowym w miastach, Międzynarodowa Konferencja Naukowa Transport XXI wieku, Prace Naukowe Politechniki Warszawskiej – Transport z. 95, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2013, s. 139-150, (in Polish), ISSN 1230-9265.
3. **Dębowska-Mróz M.** 2015. Wielkość, struktura i dynamika zmian bezpieczeństwa ruchu drogowego w Polsce i na świecie, Logistyka nr 4, s. 7370-7382 (in Polish), ISSN: 1231-5478.
4. **Dębowska-Mróz M., Rogowski, A**. 2015. Niechronieni uczestnicy ruchu drogowego – ofiary wypadków drogowych w Polsce, Technika Transportu Szynowego – koleje, tramwaje, metro 12/2015, s. 381-392, (in Polish), ISSN 1232-3829.
5. IRTAD 2016. International Road Traffic and Accident Database (IRTAD), Accident Statistics. OECD/BAST. Paris/Bergisch-Gladbach.
6. **Krystek, R. (red.)** 2009. Zintegrowany system bezpieczeństwa transportu. Tom I, Diagnoza bezpieczeństwa transportu w Polsce. WKiŁ Warszawa, (in Polish).
7. **Krystek, R. (red.)** 2009. Zintegrowany system bezpieczeństwa transportu. Tom II, Uwarunkowania rozwoju integracji systemów bezpieczeństwa transportu. WKiŁ Warszawa, (in Polish).
8. **Krystek, R. (red.)** 2010**.** Zintegrowany system bezpieczeństwa transportu. Tom III, Koncepcja zintegrowanego systemu bezpieczeństwa transportu w Polsce. WKiŁ Warszawa, (in Polish).
9. Road Safety Annual Report 2011. International Traffic Safety Data and Analysis Group, IRTAD 2011 ANNUAL REPORT OECD/ITF.
10. **Rogowski, A.** 2015. Jednoczynnikowe modele liczby ofiar niechronionych uczestników ruchu w wypadkach drogowych w Polsce, Technika Transportu Szynowego – koleje, tramwaje, metro 12/2015, s. 1310-1315, (in Polish), ISSN 1232-3829.
11. **Szczuraszek, T.** 2005. Bezpieczeństwo ruchu miejskiego, WKiŁ Warszawa, (in Polish).
12. **Tracz, M. (red.)** 2018. Wypadki drogowe w Polsce w 1990-2017 r., Komenda Główna Policji, Biuro Ruchu Drogowego, Warszawa 1999-2018 r. [online cit.: 2018-05-11]. Available from: www.policja.pl, (in Polish).

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Causes of Aviation Accidents and Incidents Especially with Engine Failure

T. Krejsa[1], V. Nemec[2], L. Hermankova[3]

[1]*University of Pardubice, Studentska 95, 53210, Pardubice, Czech Republic, E-mail: tomas.krejsa@student.upce.cz*
[2]*University of Pardubice, Studentska 95, 53210, Pardubice, Czech Republic, E-mail: vladimir.nemec@upce.cz*
[3]*University of Pardubice, Studentska 95, 53210, Pardubice, Czech Republic, E-mail: lenka.hermankova@student.upce.cz*

Abstract

Air transport is the safest and the most dynamic mode of transport but there are errors that can lead to aviation accidents or incidents. This paper deals with explanations of basic concepts in the field of aviation safety, states organizations that are involved in ensuring the safety of the aviation industry, including Safety management system. The main idea of this article is to analyze the causes of air accidents and incidents during the ten-year period, especially focusing on the causes of aircraft engine failure. Based on the identified primary causes of aircraft engine failure, authors propose measures that ultimately lead to increased safety in aviation.
KEY WORDS: *air transport, safety, aviation accidents, aviation incidents, engine failure*

1. Introduction

Air transport is the youngest and fastest growing transport sector in the world. In recent years, air traffic has seen a significant increase in transport performance, as safety and short transport times are generally known advantages of air transport. Large investments in the aviation industry have spent on discovering new technologies or innovating older technologies to improve aviation safety but there are still new air accidents and incidents that need to be eliminated in the future. To avoid the occurrence of aviation disasters, it is first and foremost necessary to thoroughly analyze the primary causes of aviation disasters that have already occurred and subsequently introduce different safety measures.

2. Safety in Air Transport

Safety is the main indicator of air transport quality. Several governmental and non-governmental organizations are involved in the operation of air transport. In general, these organizations seek to increase reliability and, above all, aviation safety. However, they also deal with other activities that are necessary for the efficient operation of air transport, including aeronautical regulations and standards, advocating the interests of airlines worldwide, the economic and environmental sustainability of the whole aviation sector, aircraft and staff certification. The main organizations include ICAO, EASA, EUROCONTROL, IATA.

In aviation legislation are listed two concepts of terminology of air transport safety. Security is the protection of air traffic from unlawful acts, for example before terrorist attacks [1]. Safety is ,,the state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level“ [2].

Efforts to continually improve the level of aviation safety resulted in the creation of a Safety management system in 2013. All aspects of the Safety management system are defined in Annex 19 (guidance is available in the Safety management manual) issued by ICAO [2].

For all civil aviation subjects the deployment of the Safety management system is mandatory and should be integrated into an organization's entire management system to describe its structure and scope, available resources, employee responsibility and decision-making across the organization [3]. For all operators and organizations are essentially identical basic principles of the Safety management system, as well as its structure and content. Differences in Safety management system arise about the size and complexity of organization and the risks unique to the operation [4].

To maintain an acceptable level of civil aviation safety, each State is required to establish a State safety programme, under which it is for each service provider to establish a Safety management system under the jurisdiction of that State. The State safety programme includes the following chapters:

- state safety policy and objectives;
- state safety risk management;
- state safety assurance;
- state safety promotion [2].

In the context of air safety, most people speak at a time when an air accident or an air incident occurs, notably in air passenger transport. Here, aviation terminology also distinguishes between air accident and incident. Air accident is an occurrence associated with the operation of an aircraft which, in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked,

or in the case of an unmanned aircraft, takes place between the time the aircraft is ready to move with the purpose of flight until such time as it comes to rest at the end of the flight and the primary propulsion system is shut down, in which:

- a person is fatally or seriously injured;
- the aircraft sustains damage or structural failure;
- the aircraft is missing or is completely inaccessible [5].

Air incident may impair the safety of air traffic operations and is associated with the operation of an aircraft [5].

3. Aviation accidents and incidents

In aviation is dedicated great attention of air accidents and incidents to increase safety. If such an event occurs, it is imperative that air accident investigators remove the primary cause in the shortest possible time to prevent these causes in the future. For investigation of air disasters, ICAO issued an Annex 13 – Aircraft Accident and Incident Investigation.

All data on air accidents and incidents are carefully recorded by aviation organizations but everyone records these data for their specific purposes. The ICAO records data in general for aviation and therefore it is possible objectively to monitor the development of serious air accidents and the number of related injuries for all.

Figure 1 shows the development of air accidents and the number of fatalities registered by ICAO [6, 7]. Fig. 1 shows that the number of air accidents variate each year, including the number of injuries, but in 2007 values are higher than in 2016 [6, 7]. The exception is the year 2014 where there was a large increase in deaths relative to death in other years, but this was mainly due to the disappearance of Boeing 777 by Malaysia Airlines 8 of March 2014, where 239 passengers were on board and Boeing 777 Malaysia Airlines 17 of July 2014, where 298 passengers were killed. It is clear that only two air accidents out of 98 will caused two-thirds of total passenger deaths in 2014.

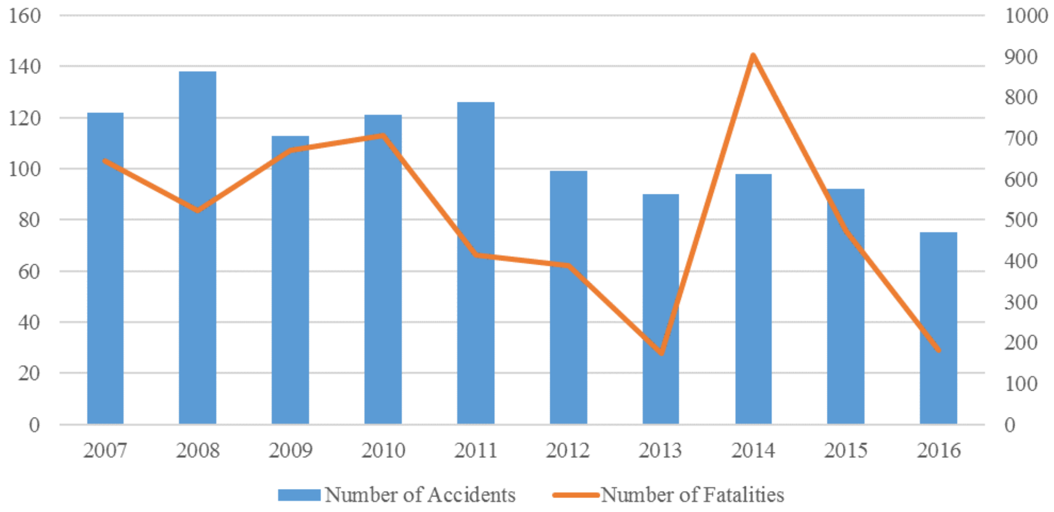


Fig. 1 Trend in aviation accidents and fatalities within ICAO

In connection with air accidents and fatalities, it is important to note that the development of passengers transported is constantly increasing, as can be seen in Table 1 [8]. It is necessary to determine whether dependence exists or not between air accidents and fatalities and the number of transported passengers. For confirmation the dependence, the authors made a correlation based on the values show in Table 1.

Table 1

Influence of air accidents and fatalities on carried air passengers

Years	Number of Accidents	Number of Fatalities	Air Transport Passengers Transported (in trillion)
2007	122	645	2,209
2008	138	524	2,208
2009	113	670	2,250
2010	121	707	2,628
2011	126	414	2,787
2012	99	388	2,894
2013	90	173	3,048
2014	98	904	3,227
2015	92	474	3,464
2016	75	182	3,696

Based on the correlation, the correlation coefficient between the number of transported passengers and the number of air accidents is **-0,867**, this means that there probably is an indirect dependence. For the number of transported passengers and the number of fatalities, the correlation coefficient is **-0,410**, there is no dependence. To confirm these results, it is important to use the test statistic namely the t-test according to the following formula [9].

$$t = \frac{r_{yx}}{\sqrt{1-r_{yx}^2}} \times \sqrt{n-2}\,, \tag{1}$$

here r_{yx} – correlation coefficient; n – range of data.

Critical field is given by inequality $| t | > t1\text{-}a / 2$, according to statistical tables it is 2,306 at the most commonly used 5% permissible error. It can be argued that between the number of transported passengers and the number of air accidents the t value is **-4.910** and is in the critical field. For the number of transported passengers and the number of fatalities the result of the test is **-1,272** and this value is outside the critical field. [9], [10]. The test statistic thus proven the indirect dependence between the number of transported passengers and the number of fatalities.

3.1. The James Reason Swiss Cheese Failure Model

The occurrence of aviation accidents or incidents can be caused by a variety of causes. To prevent the occurrence of the causes of aviation disasters in future, it is necessary to identify these causes. James Reason developed the Swiss-Cheese model, which illustrates that accidents usually involve successive breaches of multiple system defences. These breaches can be triggered by a few various factors such as equipment failures or operational errors [11]. The James Reason Swiss Cheese Failure Model is shown at the Fig. 2 [11].

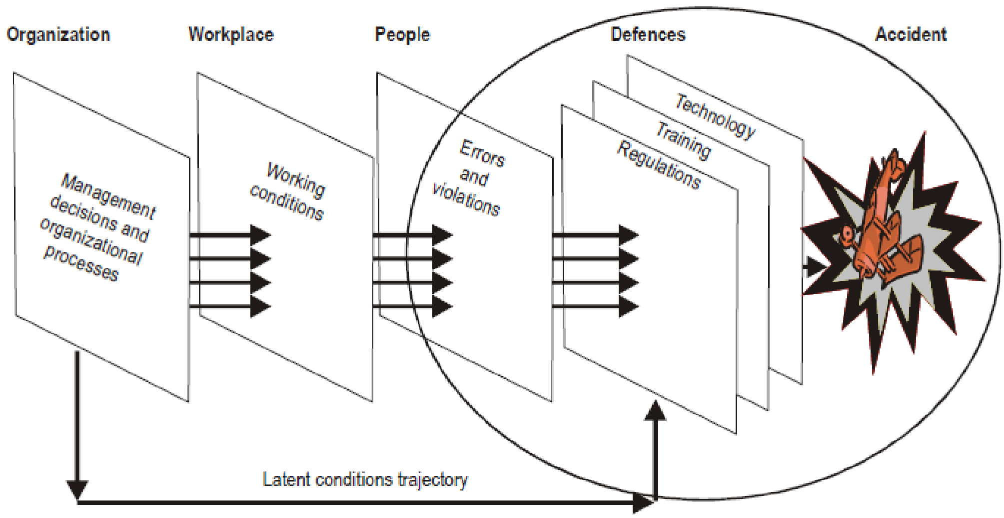


Fig. 2 The James Reason Swiss Cheese Failure Model

The model proposes that all accidents include a combination of active failures and latent conditions. Active failures are actions or inactions, including errors and violations, which have an immediate adverse effect and are generally associated with front-line personnel (pilots, air traffic controllers, aircraft mechanical engineers, etc.). Latent conditions are those that exist in the aviation system before a damaging outcome has happened. The consequences of latent conditions may remain dormant for a long time. Initially, these latent conditions are not perceived as harmful, but will become evident once the system's defences have been breached (lack of safety culture, poor equipment or procedural design, conflicting organizational goals, defective organizational systems or management decisions) [11].

3.2. Common Causes of Aviation Accidents and Incidents

Air accident statistics began to be recorded around the middle of the 20th century. It was important to record the primary cause of an air crash. Since several primary causes of air accidents can be recorded, they are divided into groups. As mentioned above, each organization records data and then breaks it into groups primarily for its needs. The authors of the article drew statistical data from the aviation safety website, as there is a very clear arrangement of groups. There are recorded all accidents including incidents from all airlines, including smaller aircraft carrying fewer passengers.

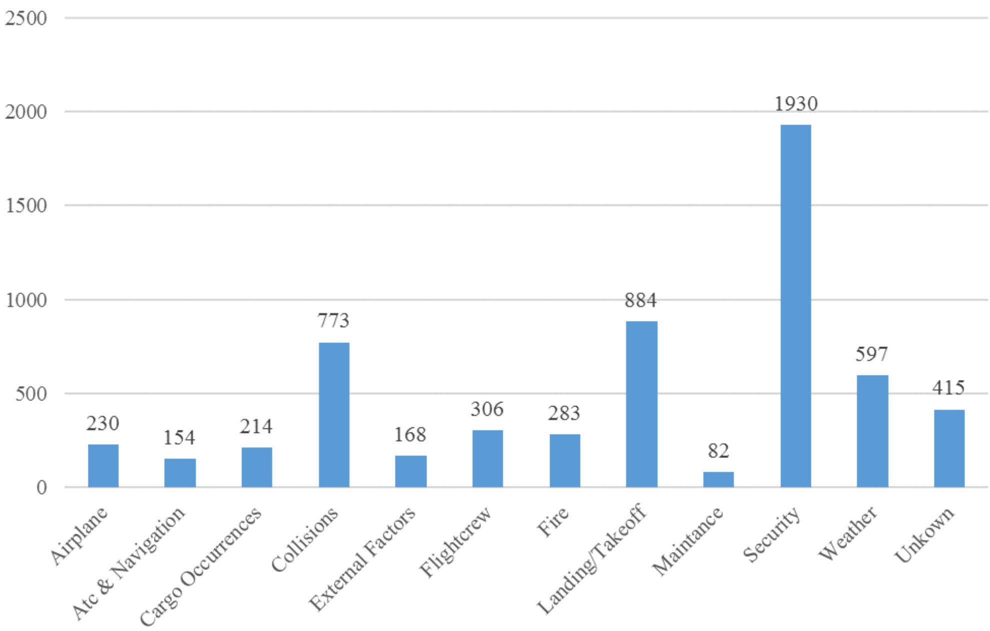


Fig. 3 Common causes of aviation accidents and incidents

Fig. 3 shows that there are 12 groups of causes of air accidents and incidents, but 11 of these groups are part of safety and only one part of security [12]. It can be argued that part of the security caused accidents and incidents considerably less than the rest of the safety groups. There were 1 930 special events in the security area, but the safety had 4 106 special events. The authors mainly deal with the causes of engine failure of the aircraft. These are causes belonging to the Airplane group (safety).

3.3. Engine Failure as a Cause of Aviation Accidents and Incidents

Engine development is not over because airlines produce a lot of pressure on engine manufacturers not only because of their reliability in operation but also because of the economic aspect. The engine can save a large proportion of aviation fuel and each flight made with these engines saves a significant portion of the cost of an airlines, particularly large Boeing and Airbus commercial aircraft. It could be reasons why engines still can cause a problem with safety in aviation.

From a safety perspective, it can be seen in Fig. 4 that the engine is the second most common causes of airplane accidents and incidents, these data are for the period 2008-2017. Airframe failure recorded higher values than engines, but the air crashes caused by the engine will have higher financial consequences for the airlines than the airframe failure [13].

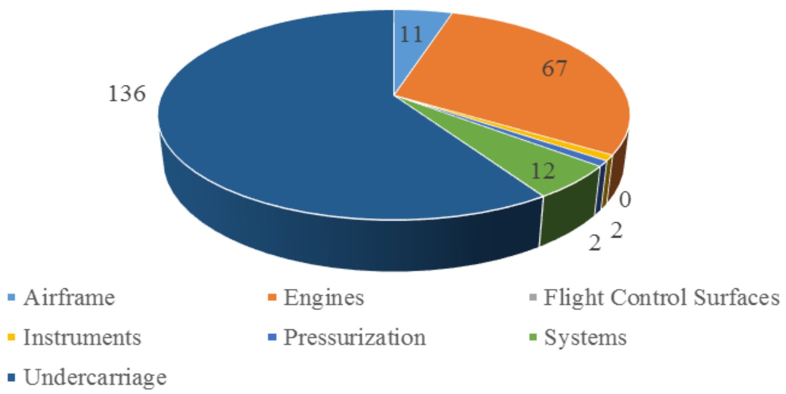


Fig. 4 Airplane causes of aviation accidents and incidents

During the last ten years (2008-2017), 67 air accidents and incidents caused by an aircraft engine can be recorded. The statistics in Fig. 5 show that failure of all engines is main of the engine causes [13]. For multi-engine aircraft, it is not a big problem to fly with one inoperable engine and then do emergency landing on close airport but in case of a failure of all engines the aircraft becomes very difficult to pilot so it is necessary to avoid this cause. Of course, this problem concerns rather smaller aircrafts that fly commonly with one engine, in large transport aircraft that have two or four engines this occurrence is very exceptional.

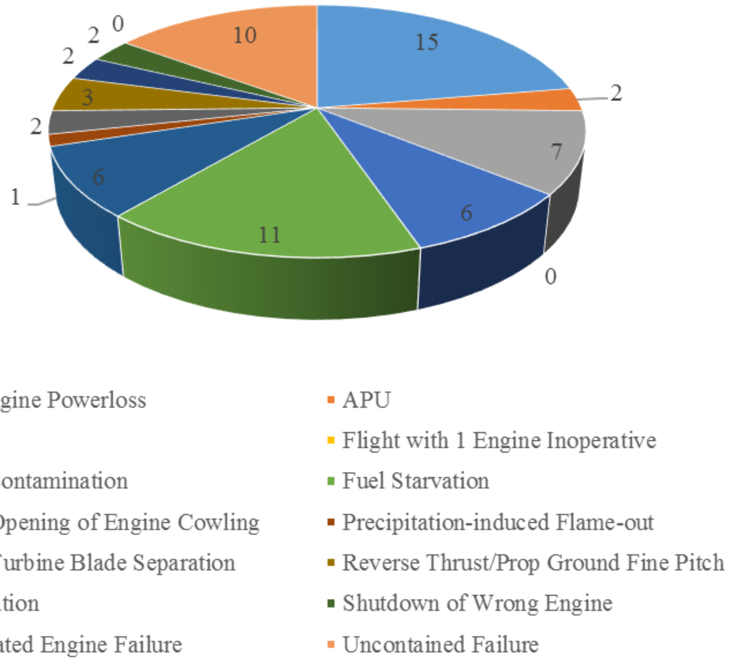


Fig. 5 Engine failure causes of aviation accidents and incidents

Fuel starvation and Uncontained failure are other very important causes, which have high number in the occurrence and they can assure the failure of the aircraft engine. Fuel starvation should eliminate the safety practices of airlines and engine manufacturers who accurately define when it is safe to fly or when it is necessary landing or refueling, which could be deplete from the tank faster (such as a strong head wind) during a flight. However, if a critical condition occurs when fuel levels are low in aircraft tanks, sophisticated computer (build in aircraft) warn crew of an aircraft, especially in large aircraft. If the fuel is depleted and the engines stopped, it is a mistake caused especially by the crew of an aircraft that does not follow the safety procedures. Therefore, it can be argued that stopping engines due to fuel starvation occurs after overcoming several safety systems (The James Reason Model).

Uncontained failure has been more detected than previous causes, but this statistic has not yet been able to record an increase in the last few months of 2018. Although this cause does not ensure usually a direct stop engine, for example, component separation may damage other parts of the aircraft (including engines) and therefore other important parts that are necessary to control the aircraft. This cause can be eliminated by performing a reliable inspection of the technical competence of the aircraft by trained personnel.

4. Conclusions

Within the identified causes of air accidents and incidents especially with engine failure, it can be argued that for increasing the safety in aviation it is needed to focus on all engine powerloss, fuel starvation and uncontained failure. These causes in the last 10 years most often caused a failure of the aircraft engine. Since the very sophisticated safety procedures and safety features of each component of the aircraft or engine are at a very high level, it is necessary to focus on what the aircraft crew should do when the engine shuts down.

If the engine is switched off on an aircraft, it is imperative that the pilot can continue to pilot the aircraft, even with limited stability. Even though pilots have practicing on flight simulators to pilot an aircraft with an inoperable one or all engine, this training is performed so that these engines are not completely switched off on the simulator but only the thrust of engines pulls down to a minimum. Authors of this article believe that training is not sufficient for pilots, as the complete disengagement of the engines will cause a much bigger problem when piloting the aircraft than just the reduced thrust of all engines (all engines are still running). Recommendations for improving safety in aviation when all engines are turned off would be if the pilots take a fly hours and practicing (for example landing) on an airplane without a motor, in a glider. Only this practical simulation will fully show the pilot how is it possible to pilot aircraft without engines.

Acknowledgements

The work was created in connection with the scientific research project of the University of Pardubice no. SGS_2018_023. The authors are grateful for their support.

References

1. Nařízení Evropského parlamentu a rady (ES) č. 300/2008 ze dne 11. března 2008 o společných pravidlech v oblasti ochrany civilního letectví před protiprávními činy a o zrušení nařízení (ES) č. 2320/2002 [online cit.: 2018-02-13]. Available from: http://eur-lex.europa.eu/legal-content/CS/TXT/PDF/?uri=CELEX:32008R0300&qid=1518263873061&from=EN (in Czech)
2. Annex 19 [online cit.: 2018-02-13]. Available from: https://www.skybrary.aero/index.php/ICAO_Annex_19,_Safety_Management
3. Civil Aviation Authority. 2010. Safety Management Systems – Guidance to Organizations. Safety Regulation Group. Version 3.
4. Civil Aviation Safety Authority. 2014. Safety Management System Basics. In Safety management system kit – Booklet 1. 2nd edition.
5. Annex 13 [online cit.: 2018-02-13]. Available from: http://www.emsa.europa.eu/retro/Docs/marine_casualties/annex_13.pdf
6. The International Civil Aviation Organization – Safety Report 2012 [online cit.: 2018-02-23]. Available from:https://www.icao.int/safety/Documents/ICAO_SGAS_2012_final.pdf
7. The International Civil Aviation Organization – Safety Report 2017 [online cit.: 2018-02-23]. Available from: https://www.icao.int/safety/Documents/ICAO_SR_2017_18072017.pdf
8. The World Bank – Air transport passengers carried [online cit.: 2018-02-26]. Available from: https://data.worldbank.org/indicator/IS.AIR.PSGR
9. **Hindls, R. et al.** 2007. Statistika pro ekonomy, Praha: Professional Publishing. ISBN: 978-80-86946-43-6 (in Czech).
10. Statistika - tabulky [online cit.: 2018-03-08]. Available from: http://statistika.vse.cz/download/materialy/tabulky.pdf (in Czech)
11. The International Civil Aviation Organization. 2013. *Safety Management Manual.* Doc 9859 AN/474. 3rd edition. ICAO: Montreal, Canada.
12. Aviation Safety Network [online cit.: 2018-03-08]. Available from: https://aviation-safety.net/database/events/
13. Aviation Safety Network – Airplane Engines [online cit.: 2018-03-08]. Available from: https://aviation-safety.net/database/events/event.php?code=AC

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Technology Aspects of Future Railway Mobile Communication System (FRMCS) in Front of Today Solutions

M. Sumiła

Railway Research Institute in Warsaw, Chłopickiego 50, 04275, Warsaw, Poland, E-mail: msumila@ikolej.pl

Abstract

The article presents the foundations of the future railway mobile communication standard (FRMCS) based on the predicted railway applications. The first part refers to the main documents issued by UIC and ETSI. The following section evokes current services implemented to the GSM-R system. In the regard to previous services it was analyzed current expectations of the FRMCS applications and their parameters. The analysis of the document [5] issued by ETSI allows to consider some selected aspects of the demand FRMCS according to the category of applications in selected railway areas. The article focuses on data transmission aspect. On this basis, the possibility of using LTE technology as a future railway technology was created. The results of this analysis ends the article.
KEY WORDS: *FRMCS, GSM-R, radio communication*

1. Introduction

Future Railway Mobile Communication System known as FRMCS is a concept and the name of a group within International Union of Railways (UIC) established to describe specifications for the successor of GSM-R solution. GSM-R (*Global System for Mobile Communication for Railways*) is nowadays a railway mobile communication standard based on well-known public mobile technology GSM 2G standard (Global System for Mobile Communications) which was modified to provide necessary functionality for effective and safe mobile communication standard used for railway purpose. Although the GSM-R networks are still not fully present in the EU countries, it is already known that rapid progress in public mobile technology and demand of railway customers will force to change the nowadays radio communication solution. In addition to this, there are already known some lacks in the operation of this network. As an example one can invoke works [11][12] in the field of coexistence of GSM-R and public mobile networks. It is anticipated that GSM-R will be supported by the manufactures till 2030. After this time the producers consider that further production of spare parts will be unprofitable. In the long term of life of using ETCS system the Railway business expect that the use of GSM-R as a medium for data transmission last until 2050. Due to this reasons in 2012 UIC decided to initiate new project to prepare the basis for choosing a next generation technology for future purpose of railway communication applications. The result this of work, issued a document named “User Requirements Specification” (URS) [13] gathering all present and predicted needs including new potential functionalities. The document does not bring a simple answer which technology is correct but allows to look at the nowadays and upcoming mobile technology from the railway point of view and its needs. General functional requirements for future applications become the basis for future work on standardization.

In the next paragraphs we are focusing on the main aspects of nowadays and future railway mobile technology, summary of predicted FRMCS services, present demands of data transmission and possibility of using present network for future services.

2. GSM-R Services in Front of FRMCS

GSM-R is the railway extension of the commercial GSM 2G telephony and has been designed specifically to satisfy railway radio communication requirements. GSM-R came into existence through consensus and cooperation of many European railways and equipment vendors. In days when GSM-R standard was developed based on the technology ie. GSM 2G was the most advanced and frequently used mobile telecommunication system in the world. Unfortunately, GSM 2G have only a few services like peer to peer voice communication, text messages and slow data transmission. UIC recognizes that the simple implementation of GSM 2G did not meet to the needs and requirements of railway companies. It would be a limitation of services used in previous railway radio communications systems used in European railways. To integrate the specific requirements of railways in the field of mobile communication some additional features had to be described, standardized and developed. All necessary services had to be incorporated into the GSM standard and were developed by MORANE group (*Mobile Radio for Railways Networks in Europe*) together with ETSI (*European Telecommunications Standards Institute*) institute. Those collaboration had a significant impact on the technical way of implementation of the standard and its’ services because the services have been borrowed from the classic wired networks. In the field of supplementary services, were used telephony standards ISDN (*Integrated Services Digital Network*) and in the field of advanced commutation methods, there was IN technology (*Intelligent Network*). The

normative and informative documents are available on UIC site [15]. These features are called Advanced Speech Call Items (ASCI) and are used for:

– Functional Addressing (FA);
– Location Dependent Addressing (LDA);
– Enhanced Multi-level Precedence and Pre-emption Service (eMLPP);
– Voice Group Call Service (VGCS);
– Voice Broadcast Service (VBS);
– Railway Emergency Call (REC);
– Originator to Dispatcher Information (OTDI);
– Late Entry.

All these services today can be treated as essential for train movement, trackside maintenance, shunting and safety applications. It seems to be enough for so called “critical services” but the future railway telephony should provide a wider spectrum of services not only for railway staff but also for other groups of users [1].

3. Demands of FRMCS Data Transmission

In the main FTRMCS document [13] from 2018, UIC pointed fundamental principles for FRMCS. Each fundamental principle was accompanied by guidance to a better understanding of the following consequences. As a result of this, FRMCS group categorizes services in the group of applications as follows: First is the type and second is the use. The type of application was categorised as:

– Comms: communication application,
– Support: supporting application of communication application(s).

The use of application was categorized as:

– Critical: applications that are essential for train movements and safety or a legal obligation, such as emergency communications, shunting, presence, trackside maintenance, ATC, etc.

– Performance: applications that help to improve the performance of the railway operation, such as train departure, telemetry, etc.

– Business: applications that support the railway business operation in general, such as wireless internet, etc.

In present requirements [13] of future applications we can find:

– 28 Critical Communication Applications,
– 20 Performance Communication Applications,
– 4 Business Communication Applications,
– 11 Critical Support Applications,
– 1 Business Support Applications,
– but there is no Performance Support Application.

It can be noted that the document [13] has changed from its previous version from 2016. The FRMCS group moved or added some services from performance communication area to critical communication field. This applies to the six applications that are associated with the transmission of multimedia data. This means that they are growing in the belief that these services will be necessary in the future railway transportation process.

All FRMCS applications have expectations regarding the functionality in the new network. There are not available any documents describing how the service will be carried out but each application have a set of parameters including:

– Type of communication for voice or data,
– Symmetry to describe a ratio between the uplink and the downlink traffic,
– Distribution to precise the type of receivers i.e. User-to-User, Multi-User or not available,
– Latency to determinate the delay between action and reaction,
– Bandwidth is a qualitative indication of the anticipated rate of data transfer when using the application,
– Speed of user movement while travelling,

– Setup is a qualitative indication of the time to establish a voice or data communication session with the application that would be acceptable to a user, and is sufficient to perform the railway operation.

– Reliability is a qualitative indication of the reliability required of the communications system when the application is in use.

The FRMCS document does not specify the values of the parameters given above. Therefore, it can be only estimated based on current knowledge. As an example one can considere the bandwidth parameter because it is the most sensitive parameter in today's mobile radio systems. It is also a quite interesting problem because it indicates the needs for network resources, ie. data transmission volume. Among indicated in [13] FRMCS document applications, wideband data transfer is especially important for implementation the performance applications which are:

– On-train telemetry communications,
– Infrastructure telemetry communications,
– Non-critical Real time video,
– Wireless on-train data communication for train staff,

– Wireless data communication for railway staff on platforms,
– Record and broadcast,
– Transfer of data,
– Transfer of CCTV archives,
– Real time video call.

To estimating volume of application needed, it is necessary to considering present knowledge on the requirements of audio and video codecs, used on-board vehicle communication standards and industrial buses. The table 1 contains comparison discussed parameter for various types of applications.

Table 1

Needs of bandwidth for types of railway applications

Type of application	**Range of bandwidth**	**Symmetry DL/UL***
Voice communication (3.1 kHz)	5.3 … 64 kbps	Yes
Voice communication (7.0 kHz)	8.85 … 128 kbps	Yes
Real time video	128 kbps … 6 Mbps	No
Train control communication	50 kbps … 2 Mbps	Yes
Telemetry	4.8 … 9.6 kbps	No
Data communication	9.6 kbps … 100 Mbps	Yes
On-train remote equipment control	4.8 kbps … 2 Mbps	No
Wireless Internet	2 Mbps … 150 Mbps	No

* DL(Downlink) / UL (Uplink)

Based on the table above, it can be concluded that at present the most of the applications' types do not require large bandwidth resources to work. Analysis presented by FRMCS group in [13] application indicated in the field of demands for bandwidth give a better knowledge of the expectations of contemporary data transmission needs. The symmetry of the channel transmission is also connected with considered parameter because the nowadays technologies often do not provide the same bit stream in each direction.

The Table 2 presents the application grouping according to the category and bandwidth to perform their services.

Table 2

Comparison of types of applications according to required bandwidth

Type of application	**N/A**	**Low**	**Medium**	**High**
Critical Communication	2	25		1
Performance Communication		11	5	4
Business Communication		2		2
Critical Support		11		
Performance Support				
Business Support	1			

Closer analysis of the types of application suggests that the most of today predicted application for FRMCS would be implemented based on the capabilities of GPRS technology in the GSM 2.5G. It means that the current GSM-R standard allows to provide most of critical applications without additional technical means. This observation does not change the fact that for multimedia applications today's GSM-R system is not sufficient.

In addition to this, it should be remembered that the values given in Table 1 refer to a single data source. In real systems we have a lot of data sources what have influence on other parameters, such as transmission latency, delay, speed of work and so one.

4. Analysis of the Use of Today Mobile Technology for FRMCS

The previous part of the article shows that a large part of the application does not require large bandwidth resources. It is therefore necessary to consider various possibilities of using modern mobile technologies. In the Technical Report (TR) [5] issued by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM) several aspects of migration present GSM-R technology to the future one were considered. Here we will invoke only traffic demands. To estimating volume of data transfer, a traffic model has been developed due to track to train communications, which is to be supported by FRMCS. The model presented in [7] has been filled with data for a number of usage scenarios and areas of operation. Results of the needed traffic volume, handling capacity for both downlink and uplink, was shown in the Table 3.

Table 3

Comparison of traffic demands according to operation conditions [1]

Area of operation	**Critical**	**Critical and performance**	**Critical, performance and Business**
	DL/UL (Mbps)*	DL/UL (Mbps)*	DL/UL (Mbps)*
Station Sztokholm	1.38 / 1.27	2.47 / 149.88	116.79 / 178.50
Station Zürich	2.88 / 1.60	4.20 / 354.63	221.74 / 409.05
Station Utrecht	2.13 / 2.03	3.09 / 216.40	135.19 / 249.45
Conventional high traffic line (4 km cell size)	1.40 / 1.40	2.10 / 150.00	90.00 / 170.00
High speed line (4 km cell size)	0.20 / 0.20	0.30 / 22.00	14.00 / 25.00

The study of the Table 3 shows that critical applications require the least resources from the other one, however the symmetry of the traffic channels is needed. The calculated in the table 3 values prove that the current GSM-R standard with implemented GPRS (*General Packet Radio Service*) technology is not sufficient for most of the applications.

The extension of the critical application range used in railway communication indicates a significant increase in traffic demand especially in the station area. Such places require extra supervision applications to improve the process of the passengers boarding and disembarking from the train. For such activities large number of cameras and sensors can be used. Depending on the size of stations and trains, uplink values can reach very high traffic values. Such was the case for Zurich stations, where uplink data transfer achieved more than 400 Mbps. With reference to Table 2, it can be seen that the number of applications of a given group does not correspond to the achieved traffic results. The number of data sources on the train, their bit rate and the need to activate in the given localization of the train are important here.

An additional aspect is the inversion of transfer volume in uplink and downlink channels in railway applications. In traditional public mobile networks and in Internet networks, wider downlink traffic is expected. In the case of railway applications, the network must provide a wideband transmission in the uplink channel from the train to network. This is necessary because this train is the source of information to the ground service.

In the search for solutions the future railway mobile communication technology, it is natural to look for known proven solutions from the public market to adopt it for railway purpose. The FRMCS Spectrum Work Group considered several approaches for future technology based on three principles [5]:

– separation of railway applications from the underlying network technologies, creating more flexibility, such as possible usage of different radio access technologies on different line categories (even within a country);

– the new radio system is to be based upon the 3GPP technology roadmap;

– for cost efficiency and migration purposes, the reuse of existing assets (radio sites, spectrum) is favored.

With regard to the earlier calculations of the demand for network traffic presented in Table 3 the only acceptable well-known today public mobile technology is LTE (*Long Term Evolution*). Based on the foundations of the technology [6] FRMCS Group developed another model according to two general aspects. One is a bandwidth block used to transmission and second is a cell size. The uplink and downlink transfers were calculated separately. The Table 4 consists obtained results.

Table 4

Data transfer in LTE according to cell size and bandwidth [7]

Cell size	**1.4 MHz**	**3.0 MHz**	**5.0 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
	DL/UL (Mbps)	DL/UL (Mbps)	DL/UL (Mbps)	DL/UL (Mbps)	DL/UL (Mbps)	DL/UL (Mbps)
0.5 km	7.99/2.32	19.60/5.69	32.68/9.64	65.29/18.83	100.57/28.53	130.62/37.81
1 km	6.00/1.74	14.70/4.27	24.51/7.23	48.97/14.12	75.43/21.40	97.96/28.36
3 km	4.80/1.39	11.76/3.41	19.61/5.78	39.18/11.30	60.34/17.12	78.37/22.68
6 km	4.00/1.16	9.8/2.84	16.34/4.82	32.65/9.41	50.29/14.27	65.31/18.90

*DL(Downlink) / UL (Uplink)

Results of calculation presented in table 3 prove that high traffic capacity available in the LTE technology is possible only for a small size of cells and for a large blocks of band. It is currently impossible in the railway network to meet these conditions for a number of reasons. The first reason is the inability to create small cells in the network for economic reasons. Small cell sizes in public networks are justified due to the large number of subscribers and the availability of infrastructure. In railway networks, the aim is to increase the size of cells. For GSM-R it is usually from 7 to 20 km. Additional calculations can be found in other document [7]. It is obvious that such future mobile network will require rebuilt the BTS infrastructure in the railway area what could be limited in the many cases.

The second major limitation is the availability of bandwidth for the needs of mobile railway communication. In

the process of creating the GSM-R system, CEPT for the first time indicated a dedicated, separated from the public, frequency band. This band was introduced in Council Directive 87/372/EEC of June 25, 1987 [2]. Today, this band is referred to as the UIC band and includes 19 ARFCN channels numbered 955 - 973. It is bandwidth is 4 MHz below public 900 MHz band. The UIC band was later extended to include an additional band of 3 MHz by the Directive 2009/114/EC [3]. In the end, it gives an opportunity to use 7 MHz band for railway purpose, now for the GSM-R network operators if a particular UE country allows to use mentioned 3 MHz extra band, what is not obligatory.

Referring to the specifications of the LTE system, it is noted that usually there is a has limited frequency block, ie. 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, etc. In UIC band it can be implemented only will 1.4 and 3 MHz bandwidth block size. In today's conditions, it allows to create a network working at about 10 Mbps.

Maximal bitrate in actually obtained band for LTE technology according to cell size presents Fig. 1.

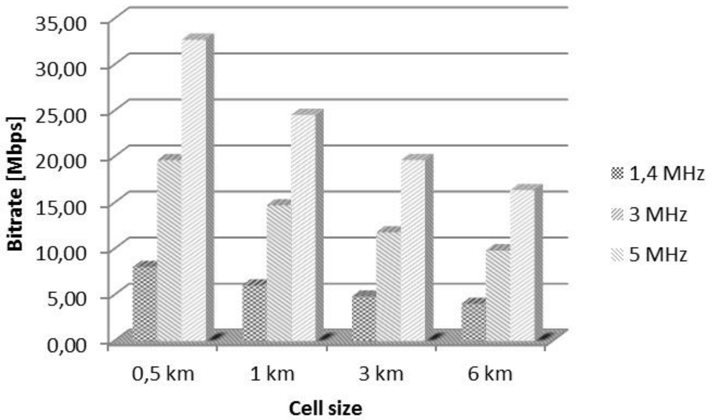


Fig. 1 Performance of LTE technology in DL channel

Regarding the previously presented restrictions the extended UIC band allow to use LTE 5 MHz bandwidth block what would improve performance of data transfer to about 16 Mbps in 6 km cells size or in case of rebuilt network and it’s cell sizes it can by obtained about 32 Mbps. The results of the spectrum prediction presented in table 3 show that presented values of transfer speed do not to meet with requirements of more demanding applications. It is obvious that LTE technology does not meet the high expectations of the new network.

5. Summary and Conclusion

The main aim of the article was to present selected aspects of the future standard of railway mobile communication regard to the current technical conditions. One of the discussed aspect was the comparison of the scope of current GSM-R application with the anticipated by the FRMCS group in document [13]. The results of this analysis shows that the new standard will have many new services in the performance and business areas. It is currently 25 new applications. At the same time, the range of critical applications has expanded.

The emergence of new applications raises a question about their specific requirements. The considerations focused on the problem of bandwidth demand. For this purpose, it was gathered information about various types of applications in terms of bandwidth demand and its uplink and downlink symmetry. Despite of the fact that only few performance and business applications requiring high data transfer, their real demands for traffic will be very high. Additionally, their introduction will require a reverse of asymmetric band in introduced radio technology. This observation is due to the high uplink traffic in the railway network in contrary to public ones. Currently, in public networks emphasis is putted on higher speeds in the downlink band because of users most of the time need to download than upload content. The above statement was confirmed by simulation tests for various areas of network used by the passing train presented in Table 3. The obtained results of the simulation were used to check the possibility of using the most advanced LTE mobile telephone technology. Carried out analyzes shows that achieving large transfers volume is possible for extend bandwidth and when the size of the cell decreases. It should be noted here that the performed analysis carried out for FRMCS also applies to other transport means where mobile communication is needed. Some of consideration connected with ITS applications was discovered in [8][9]. Ultimately, it can be concluded that there is no mature technology that can guarantee the expected level of traffic in the railway mobile network.

As a conclusion it has to emphasize that the future railway mobile system will have to face the problem of migration from GSM-R to FRMCS. The document [10] considered following scenarios:

- no migration from GSM-R to FRMCS. GSM-R technology is maintained until 2045 for the whole of Europe. This scenario is unrealistic but used as a reference in terms of cost evaluation;
- dual network GSM-R and FRMCS during a long overlap
  - dual network approach - Long overlap period but limited to of 5 years;
  - dual network approach - Long overlap period i.e. at least of 10 years;
- single network FRMCS. Rapid transition from GSM-R to FRMCS at network side with limited overlap period

(1 year). Infrastructure Manager will deploy equipment in the same time that Railway Undertaking will install new on board equipment to prepare a single network operation.

– single network FRMCS. Rapid transition from GSM-R to Next Generation at network side with limited overlap period (1 year). Railway Undertaking will install new on board equipment in advance to prepare a single network. Infrastructure Manager and Railway Undertaking finish their installation at the same time;

– dual network GSM-R and FRMCS during a long overlap (5 or 10 years) but not in the same time bandwidth (2 to 5 years) for two neighbors;

– single network FRMCS during a short overlap (1 year) but not in the same time bandwidth (2 to 5 years difference) for two neighbors.

There is no perfect solution for all railway stakeholders. It depends on the nature of the railway concerned. In general, the principle aspects that need to be considered for the implementation of a complete GSM-R system comprising fixed infrastructure and on-board equipment. The migration timeframe varied from country to country. The minimum seems for a medium size country seems to be of 4 years and a maximum in large countries is around or event more than 10 years.

References

1. **Bester, L.; Toruń, A.** 2014. Modeling of Reliability and Safety at Level Crossing Including in Polish Railway Conditions, Communications in Computer and information Science (471). Telematics – Support for Transport, Springer-Verlag Berlin Heidelberg.
2. Council Directive 87/372/EEC of 25 June 1987 on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community
3. DIRECTIVE 2009/114/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 September 2009 amending Council Directive 87/372/EEC on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community
4. EIRENE System Requirements Specification. 2016. European Integrated Railway Radio Enhanced Network. GSM-R Operators Group. UIC CODE 951. Version 16.0.0. Paris.
5. ETSI TR 103 333. 2017. System Reference document (SRDoc) GSM-R networks evolution. TECHNICAL REPORT. Ver. 1.1.1.
6. ETSI TS 136 213. 2016. Evolved Universal Terrestrial Radio Access (E-UTRA). Physical layer procedures. V13.1.1 (3GPP Release 13 LTE).
7. FRMCS SWG. 2016. FRMCS Spectrum Demand Calculation. Document No. FRMCS-SWG 15092016. Ver. 0.11. September 19.
8. **Losurdo, F.; Dileo, I.; Siergiejczyk, M.; Krzykowska, K.; Krzykowski, M.** 2017. Innovation in the ICT infrastructure as a key factor in enhancing road safety: a multi-sectoral approach. Selvaraj Henry, Grzegorz Chmaj, Zydek Dawid (eds.): Proceedings 25th International Conference on Systems Engineering ICSEng 2017, IEEE. Pp. 157-162.
9. **Siergiejczyk, M.; Paś, J.; Rosiński A.** 2014. Evaluation of Safety of Highway CCTV System's Maintenance Process, In Telematics – Support for Transport, by Jerzy Mikulski, edited by Jerzy Mikulski, 69–79, Telematics – Support for Transport. Springer-Verlag. doi:10.1007/978-3-662-45317-9_8.
10. SYSTRA 2016. Study on migration of railway radio communication system from GSM-R to other solutions. ERA 2015 04 1 RS.
11. **Sumiła, M.; Miszkiewicz, A.** 2015. Analysis of the problem of interference of the public network operators to GSM-R, Communications in Computer and Information Science, Vol. 531. Tools of Transport Telematics, Proceedings of 15th International Conference on Transport Systems Telematics. Springer, ISSN 1865-0929, ISBN 978-3-319-24576-8, Switzerland, pp. 76-82,
12. **Sumila, M.** 2016. Risk Analysis of Railway Workers Due to Interference into GSM-R System by MFCN. Communications in Computer and Information Science Vol. 640. Challenge of Transport Telematics, Proceedings of 16th International Conference on Transport Systems Telematics. Katowice-Ustroń, Poland, March 16–19, Springer Switzerland ISSN 1865-0929, ISBN 978-3-319-49645-0, DOI 10.1007/978-3-319-49646-7 2. pp. 211- 222.
13. UIC FRMCS Functional Working Group. 2018. Future Railway Mobile Communication System User Requirements Specification. FU-7100.Ver. 3.0.0.
14. UIC. 2017. FRMCS Traffic Analysis. Future Railway Mobile Communication System Architecture and Technology FW-ATwG 1903/FM56(17)030
15. UIC site: [online cit.: 2018-04-23]. Available from: http://www.uic.org/spip.php?article676

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Tribology and Reliability

J. Stodola

University of Defense in Brno, Kounicova Str. 65, 662 10 Brno, Czech Republic, and Alexander Dubcek University of Trencin, Studentska Str. 2, 911 50 Trencin, Slovak Republic, E-mail: jiri.stodola@unob.cz

Abstract

Contemporary engineering, generally Industry 4.0, referred to as the fourth industrial revolution, includes the modern trends in digitization and its associated complex automation. These changes are massively manifested in manufacturing factories, power engineering, transport, military etc. We are experiencing a phenomenon that automatic systems are more difficult to control but also more sensitive to disturbances and damage. There is a clear requirement to increase their reliability, optimal predictive maintenance, and on-board diagnostics without need of disassembly. Automated system failures can increase the risk for operators, carriers, and environmental risks in the chemical, nuclear or process industries. Failures in automated manufacturing are usually expensive for manufacturers and suppliers. Mechanical malfunctions of moving parts, friction elements, wear and seizure are one of the main reasons for a shutdown. The article deals with the role of tribology in the wider context of reliability engineering, using the theory and experience of the practice of tribology, tribodiagnostics and maintenance. These are the methods that are usable to maintain inherent reliability, or to increase the reliability of newly designed products, machines, equipment, etc.
KEY WORDS: *friction, lubrication, deterioration, tribodiagnostics, maintenance, durability, reliability engineering, synergy*

1. Introduction

Current trends include the permanent need to improve methods that allow and optimize reliability and precisely estimate the life of machines, equipment and production systems. Using modern knowledge from the theory and the application of friction processes and wear mechanisms, as well as constructing reliable friction pairs and gaining information on wear processes for different material combinations and various operating conditions, are critical to calculations and predictions of reliability. Significant tribological information, expressed in terms of technical life, probability of failure and optimal maintenance, is already available. Friction coefficient optimization (minimization), reliable wear information and appropriate material are essential to optimize the design of the machine and for the estimates of reliability. The growth of scientific information and our knowledge from nano [10^{-9}] via micro [10^{-6}] to even tera [10^{12}] contacts can become the basis for calculations, quantification and prognosis of machine reliability. This information is also a challenge for the tribological community. There are possibilities of expressing models, for example, in different geometric scales, from nano to tera tribology. With the massive growth of our knowledge, it is very likely that it will be necessary to master and mainly use other, nonlinear approaches, virtual models, numerical methods, simulation, computer support, parallel engineering, synergy, chaos theory, etc. unlike traditional strictly reduced and specialized methods in individual fields of science we are used to so far.

2. Possibilities of Increasing Reliability

There are a relatively large number of different methodologies which are usually based on expert knowledge from many technical areas but there is a need to find general solutions to reliability, maintenance and diagnostics issues. The aim is to use synergic interactions between the knowledge of experts and practitioners, to find logical contexts in analysing knowledge from different areas, often relatively remote. The starting points are expert systems, created by a computer program, which allows the recommended technical solution at expert level. This system allows the processing of non-numeric (verbal) and indefinite information. A possible systematic approach to maintaining operational reliability, increasing inherent reliability and product safety is shown in Fig. 1 [1]**.** Reliability of the human factor (operators, etc.), machinery and equipment, accidents, failures, environmental damage and other relevant negative facts can be analysed and their consequences estimated by systematic risk management methods. Critical parts of machines can be identified, the probability of failure of the system and its lifetime can be calculated, the respective costs can be determined, or estimated by statistical methods of the reliability management [2]. The identification of critical parts of the systems also allows finding tools for the improvement in the software, mechatronic and human error and failure management. In the case of finding a critical part, relevant information on residual life in fatigue wear of machine systems and their elements as test results, there are completely new approaches to the design solutions, resulting in a massive reduction of failures probability and higher probability of longer life, see Table 1**.**

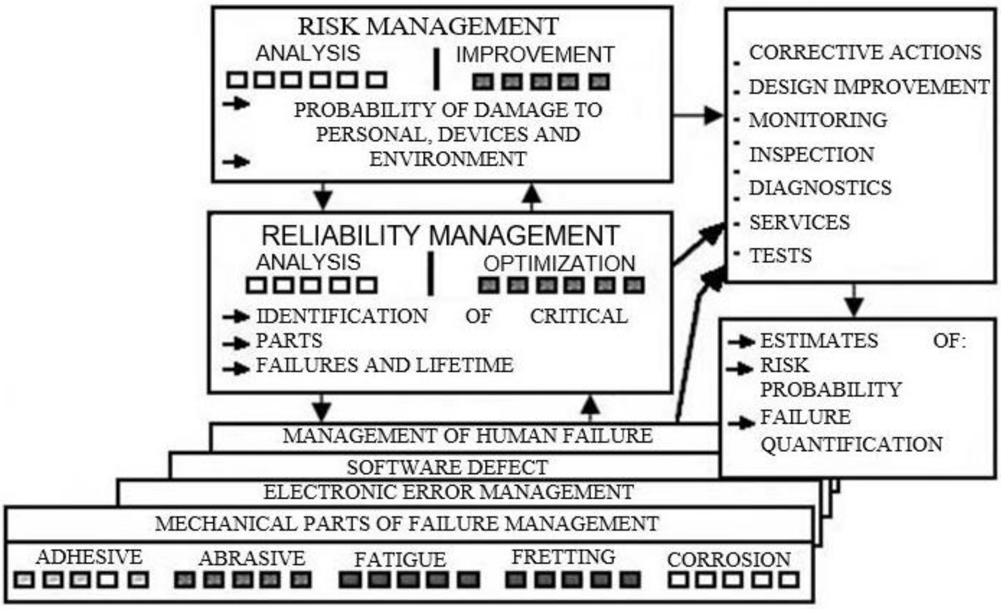


Fig. 1 Systematic approach to maintaining operational reliability and safety of products

Table 1

ANALYSIS OF OLD SOLUTIONS	RECOMMENDED AND IMPROVEMENT	UP-TO-DATE SOLUTIONS	RESULTS
regime analyse, failure analysis, experience, historical data, etc.	robust operation regime and design, new materials, monitoring and diagnostic module, simulation, etc.	new operation regime analysis, reliable design, automatic diagnostics, accelerated testing, etc.	reliable prediction of failure probability and probable lifetime, etc.

3. Reliability and Durability Components

The basic tribological complex, namely friction, wear and lubrication, includes all relationships of reliability. Friction and motion-limiting tools mean energy loss and create a prerequisite for trouble. Wearing as a material damage process also leads to malfunctions. Lubrication is a method of reduction friction and wears control that puts an additional medium between friction surfaces in motion, which reduces material and energy losses, thus reducing the likelihood of failure. There is a great challenge for the tribological community, namely: how to obtain complex tribological information about the components in mutual interaction and thus to support efforts increasing reliability? From this point of view, the specific coefficient of friction is not important, but it is important to find the conditions for finding the minimum coefficient of friction for particular friction pairs. The risk of failure occurs when the value of the coefficient of friction exceeds the standards in a particular design, and high frictional forces can cause damage. Optimum wear of the friction pair can be achieved with a particular design, but it can be massively increased during use and the wear rate for the same conditions exceeds the original design [3]. Changes in component geometry, tolerances between components with possible inaccurate or dangerous movement, etc. can occur, resulting in failures and machine shutdown. From the reliability point of view, it is necessary to obtain relevant tribological data on service life (durability, fatigue), critical wear and friction levels of components, both in general and specific operating conditions. The basic question in terms of reliability is the obtaining of tribological information from friction pairs where technical life can be quantified, or estimated. Technical life is information that allows you to determine the specific time of how long the components can be used for their intended function. Technical life specifies the critical wear level that occurs during use.

4. Information Base for Reliability Estimates (Calculation)

There are three ways to obtain the required tribological information to evaluate the technical life of parts and the risk of failure, these are:

1. collecting historical information about similar components previously operating under similar operating conditions;
2. use of generic (gender) knowledge of tribological behaviour in theoretical models, equations, simulations, etc.;
3. by laboratory testing of components of machines, on-line diagnostics of friction pairs, technology analysis, testing of materials, etc.

There is knowledge and experience gained from practice, experiments and observation of parts and more

complex units that work in similar conditions. However, the problem is that similar operating conditions may vary and be diametrically different from those to be estimated, the interpretation of the results is then uncertain. However, the main problem is the lack of information and the fact that this information is not systematically collected. Experience and historical data on machines and their components have been so far collected only for legal safety requirements. But the data should be collected during the operating process and the fault information used for reliability assessment purposes. There are deficiencies in practice, for example, the collected data are often processed by involved people. It can cause lesser credibility if their prospective position in the company can be affected by the fact whether the products are faulty or not. The solution is the emphasis on collecting historical data that can be used for the estimates of technical life, methods of automatic evaluation modules for failure rate monitoring and operating conditions directly related to working components. Quantitative assessment of friction and wear can be based on modern techniques that have more variants and levels of accuracy [4]. The same friction pairs, surface tension calculations, elastohydrodynamic contact pressure calculations, lubricating film thicknesses, etc. are currently perfectly solvable using, for example, data models. But so far, there are no fully relevant models for evaluating friction or wear in contact with, for example, structured or dyed surfaces, surfaces in the presence of fluid containing particles and wear fragments, etc. In the past, a large number of friction and wear equations were designed – e.g. for dry or limiting friction but their credibility is limited only to certain states of contacts. It seems that a promising approach using real tribological information to assess/estimate reliability will be the transition from generic wear equations to specific models of friction and wear of components. It is the use of geometric and material characteristics, relationships and parameters which allow reducing the number of ambiguous variables. Laboratory testing of various materials under specific contact conditions is a way of obtaining basic tribological information to manage reliability. In addition to technical life, the reliability parameter is very important in practical use, namely the probability of failure. Tribotechnological information can play a very important role for machine users if they obtain numerical information about technical life and probability of failure. When reliable information on ratios in friction pairs is available, it allows classification and systematic presentation, i.e. the mapping of friction and wear data**.** The map can be used for the first identification of two basic parameters, namely the speed of movement and the contact pressure. The map can be completed with windows enabling to find standard operating conditions according to the design specification of the friction pair. For example, to ensure safe operation, transition areas between different contact mechanisms and operating windows must not be achieved. Defining the operation windows in a tribological work map allows you to calculate the expected variants of technical life and the probability of failure. The result of relevant tribological information is to enable the technical life of the components to be formulated, for example, for 10 years of activity with 90% degree of certainty, or the probability of trouble-free operation over the first five years higher than 95%. This basic reliability information on friction pairs allows a relatively accurate assessment (estimation) of the machine reliability and further prospective operation.

5. Optimizing and Managing Reliability

Optimizing operational reliability, i.e. approaching inherent reliability is based on past experience from the operation of similar machines, gathering historical information about reliability, and their systematic use for improvement. It is a transformation of experience and modern knowledge from the field of machines, production, operation, maintenance according to the actual technical condition, diagnostics, documentation of the history of the machine, etc. In case reliable historical information about the new constructions is not available, the reliability is estimated on the basis of generic knowledge or from information about other machine constructions. When monitoring the operating conditions of the machine, the on-line information on the technical condition and possible functional decommissioning is obtained, for example, according to the wear of the surfaces [5], [7]. Current diagnostics allows you to obtain relevant information without dismantling. Technical status monitoring and current diagnostics are advanced and highly developed engineering activities. Technical on-board diagnostics and expert diagnostic systems include the development of autonomous sensors, systematic data collection and storage, software for the evaluation of acquired signals, signalling of ongoing processes in real time with conclusions for the diagnosis, maintenance, prediction, etc., see Tab. 2. In the area of technical diagnostics, there are many new software tools that allow automated evaluation, on-line information processing and optimal maintenance. The new support tools include expert systems, fuzzy logic, simulated annealing, genetic algorithms, neural networks, structural knowledge, etc. The procedures for diagnosing the technical conditions of the machines are based on optimized measurement procedures that allow prediction of the future state which is very important for decision where possible malfunctions would have serious consequences. Maintenance is the final part of the entire system. It includes the knowledge of the strategies of various corrective interventions that are implemented on the basis of relevant information [6]. The whole system from the detected signal to forecasting and maintenance interventions is correct only if there is relevant information about the observed phenomena. In the case of tribodiagnostics, a thorough understanding of friction and wear of friction contacts is essential. It is a solid basis for using modern diagnostic algorithms, specific procedures, tasks and reliable prognostic predictions [8], [9]. Not only the conclusions of advanced software shall be considered, but it must be a combination of diagnostic data, with knowledge of wear and failure mechanisms, trends of their development over time, etc. The most common current techniques for machine condition monitoring used today are vibratory analysis, noise analysis, ultrasonic analysis, acoustic emission, analysis of thermal fields, analysis of lubricating medium, etc.

Table 2

Sequence	Failure	Diagnostic	Data collection and analysis	Prognostics	Actions	Conclusion
	Wear Fatigue Corrosion Adhesion Catting Fretting etc.	Tribo Vibration Thermo Noise Modal analysis etc.	Preservation and data protection Statistic methods	Statistic models Expert models Scenario models Neural networks Fuzzy logic etc.	Individual approach Maintenance Repairs etc.	Status monitoring Impact analysis
Knowledge	Engineering Material science Mechanics etc.	Mechanical and electrical engineering Personal skills	Signal analysis Interpretation of results Solutions proposal	IT technology Time series Regression analysis Extrapolation etc.	Engineering Personal skills	Technical and economic knowledge

These techniques are in direct function relation to the phenomena in tribological contacts. Based on current theories, practical experience, diagnosis results, etc., two categories of maintenance can be implemented and optimized, the reactive and proactive category. Reactive maintenance is aimed at repairing the device if it fails. Proactive maintenance is focused on preventing failures and subsequent repairs by means of preventive and especially predictive methods [10]. Preventive maintenance (PM) assumes a systematic access to maintenance based on HTL (Hard Time Limits) and preventive activities. These activities are performed regardless of the current state or actual use of the machine. The aim is to prevent unplanned consequences due to failure or loss of functionality of the machine. Predictive Maintenance (PdM) includes direct tracking of the technical condition and performance of the device during operation to predict failures. The purpose is to predict the required maintenance before the machine breaks down and the functionality is lost. A suitable expression of these methodologies is shown by a potential failure (P-F) curve, see Fig. 2. Current modern maintenance trends include Reliability Centred Maintenance (RCM) methods. The RCM process is focused on maximizing the machine performance through proper lifecycle activity and optimum productivity. An organic part of the RCM is the critical analysis of the machine, related to safety, potential costs and opportunities for failure and risk occurrence.

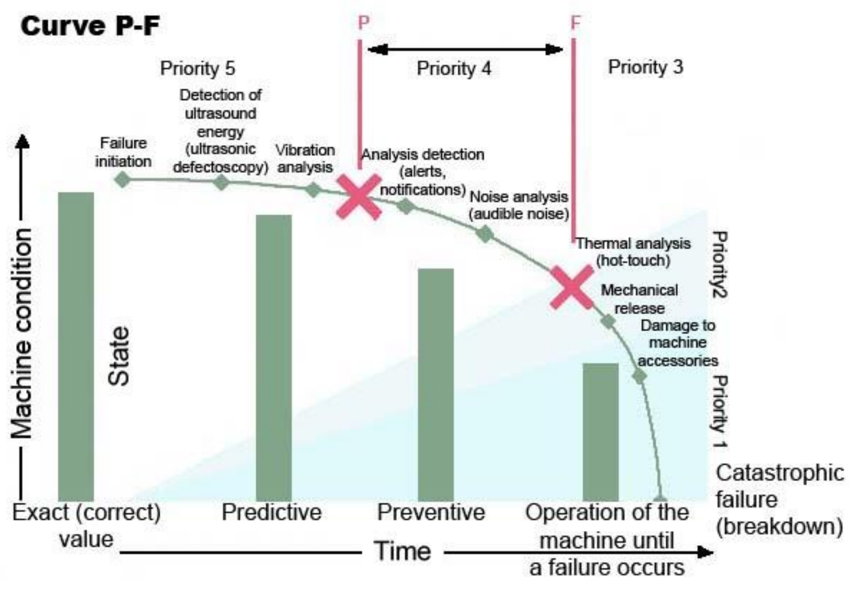


Fig. 2 Potential-Failure (P-F) curve

6. Tribology in the Reliability Structures

Modern design methods are based on maximizing efficiency, optimizing static and dynamic load, lifetime analyses, competitiveness, innovation, computer support, etc. New tools are developed to include reliability aspects of the design. One of these tools is reliability design that allows relevant predictions of the machine reliability, explicitly formed in design, construction and other pre-production phases. These methods provide designers with innovative ideas based on predicted reliability, helping the team to focus on the required reliability. Reliable design also offers the ability to analyse the customer's view and compare it with the technical possibilities achieved. Faults are estimated and classified according to historical data, probability of failures occurrence, virtual models, simulations, statistical

information, expert estimates, laboratory measurements, etc. The fault tree, which can form the basis for reliability simulation, is based on information on malfunctions, diagnostics, and prediction models. In the specific case of friction and wear-related disorders, estimates of probability of occurrence of a malfunction or probable life span over a certain life-cycle are based on relevant tribodiagnostic information. At present, it is not too common to use all available information, but the friction coefficient is almost always available and sometimes also the mechanism and the degree of wear.

7. Tribology from Nano to Tera

The relation of tribology to the reliability of mechanical systems and their unequivocal connection and relatively good availability is very important for the modern industry. However, current science and technology possibilities are new challenges increasing the amount of knowledge that is known from the research of friction and wear mechanisms, and which range from nano to tera. Possible illustration of the scaling up for friction and wear from atomic dimensions to global and cosmic universal dimensions is shown in Fig. 3 [1].

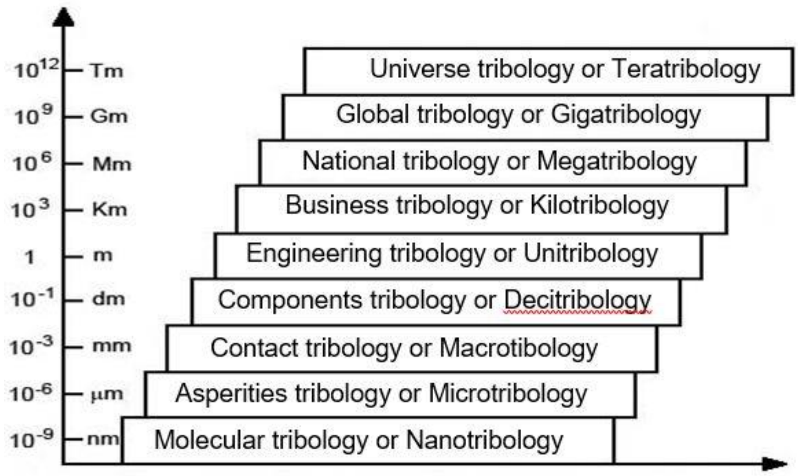


Fig. 3 Possible scheme of scale growth of tribological phenomena

In modern tribology, we can see trends leading to smaller and smaller dimensions. Nanotechnology, including nanotribology, is thriving; the scales are reduced to the basic dimensions of physical parts, i.e. molecules and atoms. These technologies are accompanied by the development and production of appropriate instruments (atomic microscopy, tribometers, etc.) to study friction and wear on a molecular scale, measuring the friction forces between contact atoms at the nano-Newtonian level. The possibilities of information technologies (software, hardware) allow the study of friction, wear and other associated phenomena using simulations of molecular dynamics of friction surfaces and the research of contact mechanisms on an atomic scale [11]. Growing knowledge of tribological phenomena at a nanoscale leads to a massive increase in knowledge, relevance of predictions about friction and wear throughout the life cycle. It can be stated that scale-up from molecular phenomena to space tribology shows that all levels of the dimensions are generally known and the scales are only relative [12]. However, this statement can pose a significant risk. It is connected with the impression that the whole world is a mechanical system, and if we know all the details from the subatomic level, we logically know all the laws, not only technical but also social. Of course, this is not a mechanical system, interactions are much more complex, but it is true that a reducing approach is used in many special sciences including tribology, reliability, etc. This is a reduction of the system that we are studying to the minimum number of the most basic elements and then trying to understand this reduced system. This methodology has been massively and relatively successfully used. However, the development of society and new scientific knowledge make it possible to understand complex systems more thoroughly, using overlaps and interactions of technology with life sciences, social sciences, artificial intelligence, information technology, etc. This approach brings qualitatively new knowledge that leads to the conclusion that reducing and isolated approaches cannot explain the behaviour of large complex systems.

8. Conclusion

Research and understanding of friction, lubrication and wear, from historical information to contemporary modern theory, knowledge gained through modelling, simulation, testing and practice, create a vast database of reliable information for different combinations of materials, loads and operating conditions. This is essential to determine the inherent reliability of the new machine and its operational reliability at various stages of the life cycle. Tribological information can then be expressed by numerical values of technical life and probability of failure. Friction coefficient values and actual wear mechanisms are essential for optimal design, choice of suitable materials, but also for reliability

estimates. It is of great importance to increase the scale of knowledge for estimates of the development of reliability characteristics. In practice, it is possible to express tribological interactions for various geometric scales, ranging from nano to tera scale. Further development of our knowledge will require the use of other, seemingly unrelated, science disciplines, virtual models, simulations, nonlinear approaches, etc. which will limit the reductions as hitherto customary in special sciences.

Acknowledgement

Presented work has been prepared with support of the project MOBAUT, University of Defense Brno, Czech Republic

References

1. **Holmberg, K.** 2000. Reliability Aspects of Tribology, 9th Nordic Symposium on Tribology. NORDTRIB 2000 3: 787 -804.
2. **Werner, B.T.** 2000. Complexity in Natural Landfoorm Patterns, Science 284: 102-104.
3. **Bowden, F.P.; Tabor, D.** Friction and Lubrication of Solids. Part I, Oxford U.P. 321 p
4. **Briscoe, M.H.** 1990. Why space tribology? Tribology international. Elsevier 1990, Volume 23, Issue 1990, pp 67-74.
5. **Hamatrock, J,B.; Schmidt, R.S.; Jacobson, O.B**. 2004. Fundamentals of Fluid Film Lubrication. McGraw-Hill, 2004, Second Edition, ISBN 0-8247-5371-2 699 p
6. **Rausland, M.; Hoyland, A**. 2004. System Reliability Theory. John Wiley & sons, INC. 2004, Second Edition, ISBN 0-471-47133-X 636 p.
7. **Bieresaw, G.; Mittal, L.K.** (Editors). 2008. Surfaces in Tribology. CRC Press. ISBN 978-1-4200-6007-2 461 p.
8. **Takadum, J.** 2007. Materials and Surface Engineering in Tribology. John Wiley & sons, INC. ISBN 987_1_84821-067-7 226 p.
9. **Khonsari, M., Booser, R, E.** 2001. Applied Tribology - Bearning Design and Lubrication. John Wiley & sons, INC. ISBN 0-471-28302-9 496 p
10. **Janicek, P.** 2007. Systemic Conception of Selected Fields for Search Techniques. Part I and II. VUTIUM, Brno. ISBN 978-80-7204-554-9 1230 p (in Czech)
11. **Novotny, P.** 2017. Thrust Bearing – Analysis and Design Proposals. Technical university in Brno. pp 1-32.
12. **Müller, G.** (Editor) 2006. Ceramics - processing, reliability, tribology and wear. Wiley-VCH Verlag GmbH. ISBN 978-3527-301-94-2

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Effects of Load Cell Wall Design in the Assessment of Shape Compatibility in Vehicle Collisions

S. Himmetoglu

Hacettepe University, Beytepe 06800, Ankara, Turkey, E-mail: s.himmetoglu@hacettepe.edu.tr

Abstract

Override/underride crashes are a typical shape incompatibility problem which stems from the differences in the height of main energy absorbing structures of vehicles. In order to assess the risk of shape incompatibility, full-width rigid barrier (FWRB) crash tests under the New Car Assessment Program (NCAP) are utilised to determine the average height of force on the barrier with the aid of load cells attached to the barrier. This paper evaluates the differences in the average height of force values between single-axis and multi-axis load cell walls or barriers regarding the most recent FWRB crash tests. For four different vehicle types (3 passenger cars, 1 SUV, 1 light truck, 1 van), average height of force is calculated with and without moments recorded by the load cells. Load cell walls with different resolutions are also investigated to see the differences in average height of force values based on load cell size. It is observed that the average height of force values do not change significantly when moments from the load cells are taken into consideration for higher resolution load cell walls. The results of this study is a useful guide to design cost-effective load cell walls which can accurately measure average height of force in order to investigate shape incompatibility between vehicles.
KEY WORDS: *vehicle safety, compatibility, average height of force, load cell*

1. Introduction

Shape incompatibility (or geometric incompatibility) is a serious problem increasing the severity of vehicle collisions. Cars can earn good ratings in consumer crash tests but they may perform poorly in real-world accidents due to a lack of good compatibility with other cars. The differences in the masses and stiffnesses of the colliding vehicles create incompatibility between vehicles, but there can also be shape incompatibility between vehicles. In an accident involving colliding vehicles, shape incompatibility occurs when there is a lack of geometric alignment of energy-absorbing structures of the vehicles coupled with differences in the respective strengths of these geometrically mismatched structures. There is usually a lack of shape compatibility in override/underride crashes, side impacts, oblique impacts and offset crashes. Therefore, the height of the main energy absorbing structure of a vehicle is an important parameter to assess shape compatibility. The main energy absorbing structure in frontal impacts is the two longitudinal members between the bumper and the firewall.

Passenger cars are typically at a disadvantage when they collide with SUVs and LTVs (Light Trucks and Vans) which tend to be heavier, taller and have stiffer front structures. In such override/underride crashes, the energy-absorbing structures of the taller and lower vehicles are not able to engage or meet, thus significant intrusion into the occupant compartment of the lower vehicle becomes much more likely.

The National Highway Traffic Safety Administration (NHTSA) conducts full-width rigid barrier (FWRB) crash tests under the New Car Assessment Program (NCAP). In these tests, the rigid barrier (i.e. wall) is composed of load cells measuring the crush forces and/or moments acting on the vehicle. The load cell data is used to determine the crush force distribution on the wall during the impact and calculate the average height of force from the ground which is considered as one of the key metrics to assess shape compatibility between vehicles especially in override/underride crashes.

Five or six years ago, the load cells used in FWRB crash tests were mostly single-axis type measuring forces only; thus an engineer had to assume that the crush force was applied at the geometric centre of each load cell in the analyses although the crush force is nonuniformly distributed across the load cell surface. In order to better represent the force distribution on the rigid wall and to calculate more accurately the average height of force, load cells with moment measuring capability (i.e. multi-axis load cells) are used in the last 5 or 6 years. It is now common practice to use load cells with 125 ×125 mm dimensions in FWRB NCAP tests [1]; using such high resolution load cell walls decreases the error in the value of average height of force [2] but it should be investigated whether the use of multi-axis load cells make any difference in the average height of force value in comparison to single-axis load cells in such high resolution load cell walls.

2. Shape Incompatibility in Override/Underride Frontal Crashes

In override/underride frontal crashes, the energy absorbing structures of the colliding vehicles have poor structural interaction and typically the taller vehicle overrides the lower vehicle. Such an accident is shown in Fig. 1 in which a light truck overrides a passenger car with 100% overlap leading to considerable deformation of the occupant compartment of the passenger car. In Fig. 1, the longitudinal member top and bottom heights of the light truck are 525 mm and 426 mm

whereas the longitudinal member top and bottom heights of the passenger car are 476 mm and 367 mm respectively, thus there is a height difference of about 100 mm between the longitudinal members which are the principal (or primary) energy absorbing structures (PEAS) of the vehicles [1]. In frontal crashes such as the one shown in Fig. 1, the PEAS of the vehicles do not meet well and the crash energy is not absorbed effectively by the PEAS, hence the occupant compartment of the lower vehicle, which is comparatively less stiff with respect to that of the taller vehicle, is forced to absorb a considerable amount of crash energy leading to larger occupant-compartment intrusion in the lower vehicle [3, 4]. In override crashes, excessive bending of the PEAS can occur which reduces the energy absorbing capacity of the PEAS and forcing the occupant compartment to deal with most of the crush energy [4].

a b c

Fig. 1 Override/underride frontal crash: a - before impact; b - at maximum deformation; c - during rebound [1]

In order to mitigate the adverse effects of override/underride frontal crashes, the structural interaction between the front-ends of the vehicles must be improved. This is especially essential for medium and high severity crashes to reduce injuries and fatalities. As a first remedy to reduce shape (or geometric) incompatibility, the PEAS of the taller vehicles can be lowered to ensure engagement of the PEAS of both smaller and larger vehicles. For this reason, NHTSA established a regulation which specifies a bumper interaction zone (Part 581) of 16 to 20 inches (406 to 508 mm) above the ground to provide shape compatibility [1, 5]. In order to improve structural interaction, additional load paths in the front-end structures of vehicles are being constructed. For instance, light trucks are equipped with secondary energy absorbing structures (SEAS) installed below the PEAS and behind the bumper [4, 5]. Additional load paths provide a more homogenous force distribution vertically on the front-ends of the colliding vehicles thus improving structural interaction. Force homogeneity can be obtained by mounting SEAS, subframes, enlarged bumper beams, cross members (e.g. as a radiator support) and shotguns [3, 4, 6, 7]. Improved structural interaction obtained by providing similar PEAS (or bumper) height and force homogeneity, increases energy absorption by the front-end structures and reduces occupant compartment deformations of the colliding vehicles [3, 8].

3. Load Cell Wall Design and Calculation of Average Height of Force

Average height of force (from the ground) acting on the vehicle and force homogeneity assessment at the front-end of the vehicle are the key metrics to assess shape compatibility in frontal crashes [3, 5, 6]. It is common practice to calculate average height of force with the aid of load cells in FWRB NCAP crash tests [1, 5]. In FWRB crash tests, cars impact a fixed rigid barrier (i.e. fixed rigid wall) with 100% overlap (i.e. full-width) at a fixed impact speed of 56 km/h as shown in Fig. 2. The rigid wall surface is covered with an array of load cells, as shown in Fig. 3, measuring the crush forces and/or moments acting on the vehicle. The forces and moments recorded by the load cells are filtered according to the Society of Automotive Engineers (SAE) Recommended Practice J211-1 to remove the noise in the raw data [10].

Fig. 2 FWRB frontal impact test [1]

The load cells can be single-axis or multi-axis type. Single-axis load cells measure forces only in the x-direction of the global coordinate system shown in Fig. 2, therefore in data analysis it is considered that the crush force is applied at the geometric centre of each load cell and this creates some errors as described in the following sections. In multi-axis load cells, both crush forces and moments are recorded, therefore it is possible to locate the true point of application of the resultant force acting on the load cell. In Fig. 4, a multi-axis load cell is depicted which measures three forces and two moments in mutually perpendicular axes by using four pressure sensing nodes.

In the literature, the average height of force is denoted by AHOF [5]. However, the term AHORF (Average Height of Resultant Force) is used in this paper to replace AHOF since AHORF is a better description as described below. In order to calculate the AHORF acting on the vehicle in FWRB crash test, the following procedure is applied.

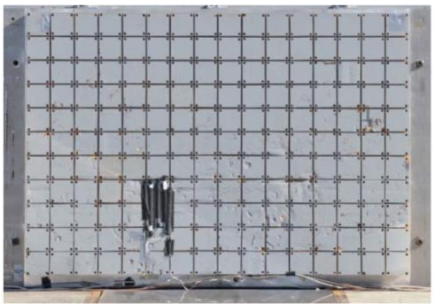


Fig. 3 Load cell wall [1]

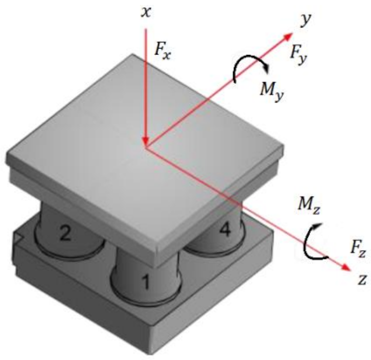


Fig. 4 A multi-axis load cell (adapted from [11])

In multi-axis load cell wall, each load cell records the total force $\vec{F}_i = F_i\vec{\imath}$, the resulting moments $\overrightarrow{My}_i$ and $\overrightarrow{Mz}_i$ acting on the corresponding section of the vehicle as shown in Fig. 5. Therefore, with the aid of the moments, it is possible to determine the point of application C_i of the total force $\vec{F}_i$ for load-cell i as shown in Fig. 5. The geometric centre of load-cell i is denoted by O_i. The position of C_i with respect to O_i is given by the vector $\vec{r}_{O_iC_i}$ whose components are calculated by using Equation 1. The position of O_i with respect to the centre O of the fixed ground frame $\mathcal{F}_O$ is represented by $\vec{r}_i$ as shown in Fig. 6. Once $\vec{r}_{O_iC_i}$ is determined, the position of C_i with respect to O is given by $\vec{R}_i$ in Equation 2. The local reference frame of each load cell, which is drawn in grey, is parallel to the fixed ground frame $\mathcal{F}_O$ as shown in Fig. 5 and Fig. 6.

$$\vec{r}_{O_iC_i} = d_{iy}\vec{\jmath} - d_{iz}\vec{k},\ \ \vec{r}_{O_iC_i} \times \vec{F}_i = \overrightarrow{My}_i + \overrightarrow{Mz}_i = My_i\vec{\jmath} + Mz_i\vec{k},\ \ d_{iz} = -My_i/F_i,\ \ d_{iy} = -Mz_i/F_i; \tag{1}$$

$$\vec{r}_i = r_{iy}\vec{\jmath} - r_{iz}\vec{k},\ \ \vec{R}_i = \vec{r}_{OC_i} = \vec{r}_i + \vec{r}_{O_iC_i} = (r_{iy} + d_{iy})\vec{\jmath} - (r_{iz} + d_{iz})\vec{k} = R_{iy}\vec{\jmath} - R_{iz}\vec{k}. \tag{2}$$

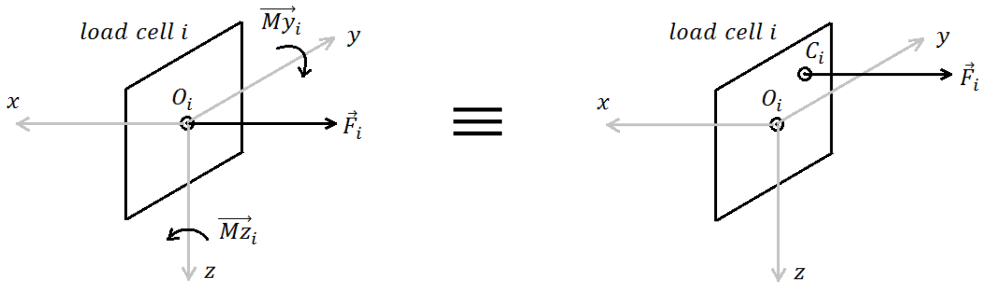


Fig. 5 Total force and moments measured by each load cell

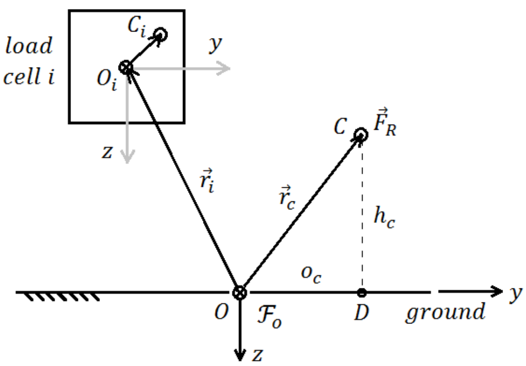


Fig. 6 Frames and points for load-cell i

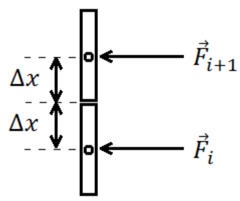


Fig. 7 Discretization error in single-axis load cells

The next step is to find the resultant force $\vec{F}_R$ for the whole load-cell wall and the point C where $\vec{F}_R$ acts as shown in Fig. 6. The position of C with respect to O is given by $\vec{r}_c$. In Fig. 6, h_c is the height of the resultant force (HORF) from the ground and o_c is the offset of resultant force from the z-axis of the fixed ground frame $\mathcal{F}_O$. Equations 3 and 4 show the calculation of $\vec{F}_R$, h_c and o_c.

$$\vec{F}_R = F_R\vec{\imath} = \sum \vec{F}_i\ ,\ \ \vec{r}_c = \overrightarrow{OC} = o_c\vec{\jmath} - h_c\vec{k}\ ,\ \ \sum(\vec{R}_i \times \vec{F}_i) = \vec{r}_c \times \vec{F}_R; \tag{3}$$

$$h_c = HORF = (\sum R_{iz}\, F_i)/F_R\,, \quad o_c = \left(\sum R_{iy}\, F_i\right)/F_R. \tag{4}$$

The values of F_R, h_c and o_c are calculated at all time instants of the crash. In order to find the AHORF (Average Height of Resultant Force) of the vehicle, the values of F_R are multiplied by their corresponding HORF (i.e. h_c) values at all times and then summed, and then divided by the sum of all values of F_R as shown in Equation 5. Thus, AHORF is a weighted average of HORF values. In the AHORF formula, F_R and h_c are usually written as a function of d which represents vehicle crush [2].

$$AHORF = (\sum F_R(d) h_c(d))/\sum F_R(d). \tag{5}$$

The AHORF value is calculated for the first 25 mm to 400 mm of the crush and that is why it is denoted by AHOF400 in the literature [2]. However, in this study AHOF400 is replaced by AHORF25400 since it is a clearer representation. Typically in the first 25 mm of crush, the crush forces are relatively much smaller and the noise in the recorded data can produce unreliable and unrealistic HORF values. Crosstalk occurrence and distortions by the bandpass filters are also cited as sources of error in HORF in the early stages of impact [2]. In order to have consistent comparison of vehicles, AHORF is calculated up to 400 mm of crush and engine contact with the wall typically occurs after 400 mm of crush in FWRB crash tests, hence this upper limit of 400 mm crush is also considered to isolate the high crush-forces as a result of engine contact [2].

Several studies have shown that using single-axis load cells might cause considerable errors in the calculation of AHORF [2, 5, 6]. In walls composed of single-axis load cells, the main problem is the discretization error as shown in Fig. 7 where Δx is the half length of the load cells. If a part of vehicle structure contacts the load cell at around its edge, this contact or crush force will be registered as a crush force acting at the geometric centre of the load cell. Hence, the maximum discretization error in the height of the local force is Δx; this is similar to round-off errors in computer storage of numbers. Therefore, it can be seen that load-cell size (i.e. load-cell wall resolution), height of the load-cell wall from the ground, the geometry of the vehicle structure, size of the vehicle structure contacting the load-cells are the factors that affect the accuracy of AHORF value [2, 6, 12]. Therefore, to eliminate adverse effects of these factors, multi-axis load-cells should be used to calculate accurately the AHORF [2].

4. Calculation of AHORF25400 – Single-Axis Versus Multi-Axis Load-Cell Walls in Recent Crash Tests

In order to investigate the effects of load-cell wall resolution and moment measuring multi-axis load cells on the value of AHORF25400, four different recent vehicles (3 passenger cars (PC), 1 SUV, 1 light truck (LT), 1 van) were selected from the crash database of NHTSA [1]. In all of these six recent FWRB crash tests, the rigid wall consists of load cells with 125x125 mm dimensions and the load cell matrix is composed of 11 rows and 16 columns having a total of 176 load cells as shown in Fig. 8. Table 1 presents information about these six vehicles which include longitudinal member top height (LMTH) in mm's and engine placement.

Table 1

Set of vehicle properties

Vehicle	LMTH (mm)	Engine Placement
PC1	510	Front-Transverse
PC2	510	Rear-Transverse
PC3	564	Front-Longitudinal
SUV	625	Front-Transverse
LT	635	Front-Longitudinal
Van	575	Front-Transverse

In all of these six crash tests, multi-axis load cells are used with moment measuring capability. In the data analysis, AHORF25400 is first calculated without moments as if the load cells were single-axis. In the next step, AHORF25400 is calculated using moments. In the final step, each group of four adjacent load cells is regarded as one load cell with 250x250 mm dimensions to create a coarse load-cell matrix; this new load cell matrix is composed of 5 rows and 8 columns having a total of 40 single-axis load cells as shown in Fig. 8. In the coarse load-cell matrix, the top row of the original load cell matrix has to be disregarded; this is a reasonable approach since the top row does not have any contact with the structures of the vehicles. Algorithms are written in Matlab to perform automatically all these analyses and calculate AHORF25400. The load cells are numbered according to the reading order of the load cell data. For instance, 1st, 2nd, 17th and 18th load cells are grouped together to form a new group of load cells in the coarse load-cell matrix as shown in Fig. 8.

For each vehicle, Fig. 9 and 10 show HORF25400 which is the height of resultant force as a function of crush (i.e. vehicle deformation) in the range 25 mm to 400 mm. In Fig. 9 and 10, HORF25400^{s} and AHORF25400^{s} values are obtained using single-axis 125 × 125 mm load cells; HORF25400^{m} and AHORF25400^{m} values are obtained using multi-

axis 125 × 125 mm load cells; HORF25400^{c} and AHORF25400^{c} values are obtained using single-axis 250 × 250 mm load cells. Table 2 shows the AHORF25400 values for all vehicles and for all types of load-cell matrices including standard deviations (SD) and longitudinal member top heights (LMTH).

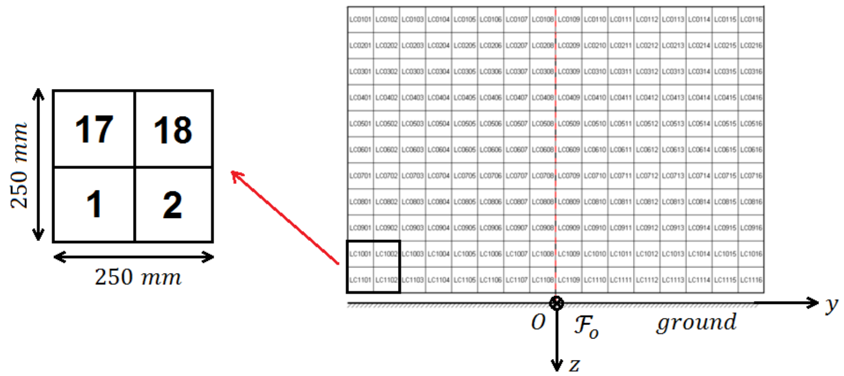


Fig. 8 Load cell matrix with 11 rows and 16 columns

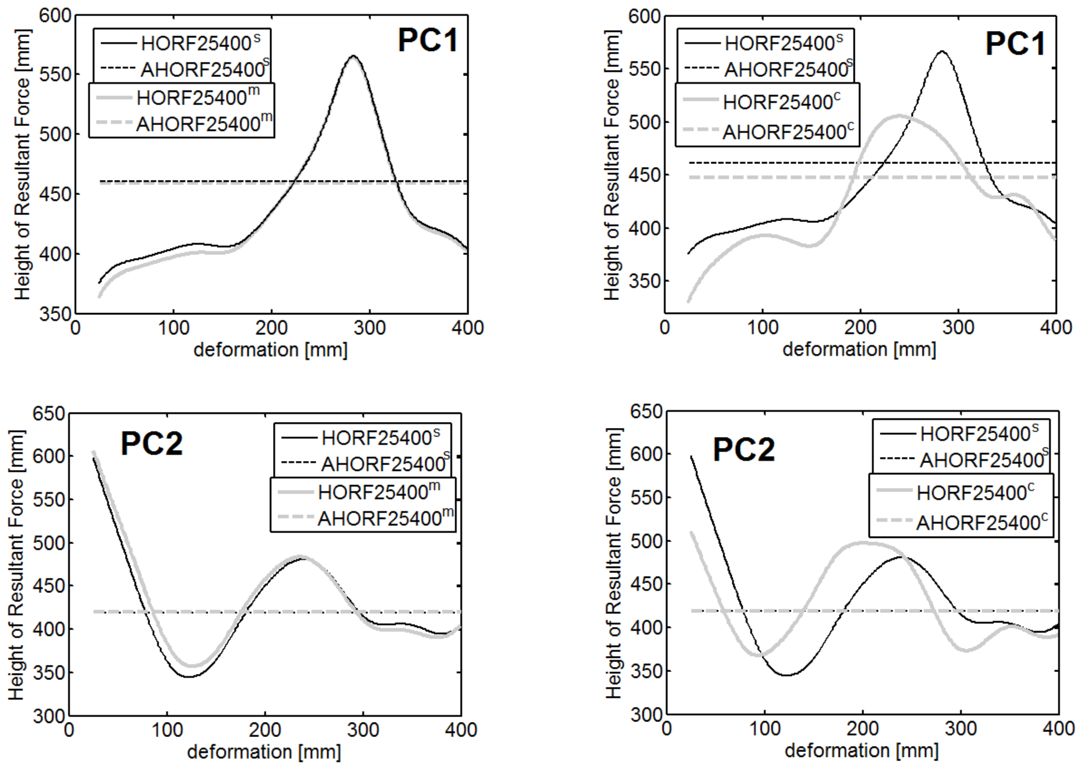


Fig. 9 AHORF25400 values and variation of HORF25400 (see Tables 1 and 2)

Table 2

AHORF25400 values and corresponding standard deviations (SD)

Vehicle	**AHORF25400** 125 × 125 mm single-axis load cells	**AHORF25400** 125 × 125 mm multi-axis load cells	**AHORF25400** 250 × 250 mm single-axis load cells	**LMTH**
PC1	461.01 mm (SD: 54.88 mm)	458.92 mm (SD: 57.08 mm)	447.39 mm (SD: 50.42 mm)	510 mm
PC2	419.41 mm (SD: 52.32 mm)	420.93 mm (SD: 54.65 mm)	419.43 mm (SD: 45.87 mm)	510 mm
PC3	532.48 mm (SD: 74.85 mm)	534.06 mm (SD: 73.47 mm)	497.27 mm (SD: 60.77 mm)	564 mm
SUV	516.68 mm (SD: 33.90 mm)	513.26 mm (SD: 34.33 mm)	490.68 mm (SD: 32.23 mm)	625 mm
LT	565.77 mm (SD: 45.24 mm)	562.15 mm (SD: 50.21 mm)	559.69 mm (SD: 44.95 mm)	635 mm
Van	552.03 mm (SD: 37.90 mm)	544.25 mm (SD: 38.39 mm)	513.30 mm (SD: 21.24 mm)	575 mm

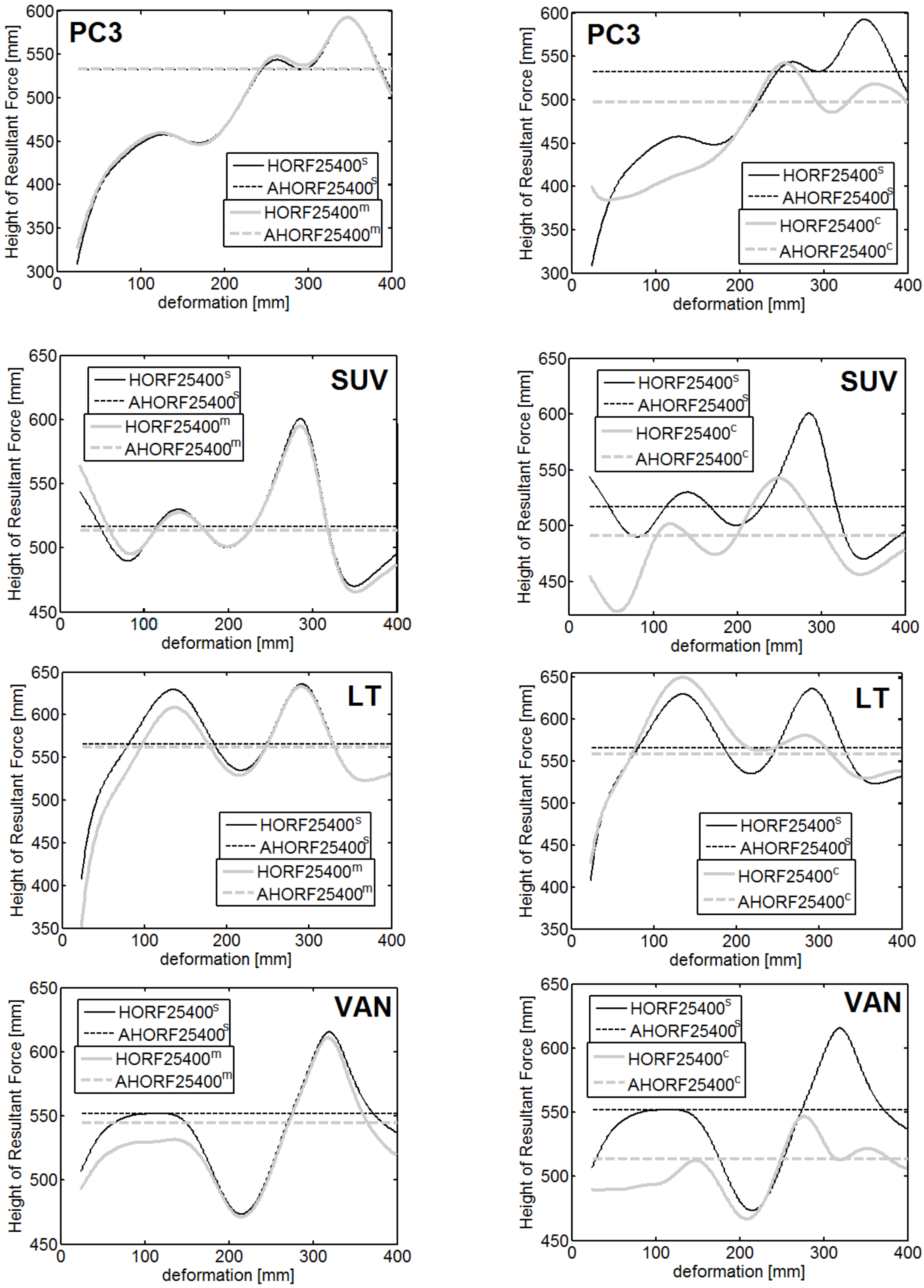


Fig. 10 AHORF25400 values and variation of HORF25400 (see Tables 1 and 2)

5. Discussion

True AHORF values can be obtained by using multi-axis load-cell walls. In this study, AHORF calculation for multi-axis load cell walls is performed using Eqs.(1) to (5) which is different but an equivalent procedure compared to the one given in reference [5]. Using the results given in Table 2, Fig. 9 and Fig. 10, the following interpretations can be made in which the true error is equal to AHORF25400^m minus AHORF25400^s (or AHORF25400^c).

In the FWRB NCAP crash test reports [1], only the top heights of longitudinal members (LMTH) are given, but typically there is difference of 100 mm between the top and bottom heights of longitudinal members for the vehicle types investigated in this paper [5]. Therefore, an average height of longitudinal member (AHLM) is defined which is 50 mm less than the LMTH values given in Tables 1 and 2.

For the passenger car PC1, the true error of AHORF25400^s is -2 mm; the true error of AHORF25400^c is 11.5 mm; all AHORF25400 values are within the Part 581 bumper regulation zone; the difference between AHLM and AHORF25400^m is only 1 mm; thus longitudinal member height is well correlated with AHORF25400^m.

For the passenger car PC2, the true error of AHORF25400^s is 1.5 mm; the true error of AHORF25400^c is 0 mm (by chance); all AHORF25400 values are within the Part 581 bumper regulation zone; the difference between AHLM and AHORF25400^m is 39 mm.

For the passenger car PC3, the true error of AHORF25400^s is 1.5 mm; the true error of AHORF25400^c is 36.8 mm; AHORF25400 values are out of Part 581 bumper regulation zone (except the coarse load-cell wall); the difference between AHLM and AHORF25400^m is -20 mm; standard deviations for HORF25400 variation are higher than those of PC1 and PC2; the shape of the HORF25400 graph is considerably distorted for the coarse single-axis load-cell wall.

For the SUV, the true error of AHORF25400^s is -3.5 mm; the true error of AHORF25400^c is 22.6 mm; AHORF25400 values are slightly out of Part 581 bumper regulation zone; the HORF25400^c graph is shifted downward in comparison to HORF25400^m which is the true variation of height of resultant force; the difference between AHLM and AHORF25400^m is 62 mm; thus it can be said that this SUV is expected to have SEAS that lower AHORF25400^m towards the Part 581 bumper zone.

For the light-truck LT, the true error of AHORF25400^s is -3.6 mm; the true error of AHORF25400^c is 2.5 mm (by chance); AHORF25400 values are out of Part 581 bumper regulation zone; the difference between AHLM and AHORF25400^m is 23 mm.

For the van, the true error of AHORF25400^s is -7.8 mm; the true error of AHORF25400^c is 31 mm; AHORF25400 values are out of Part 581 bumper regulation zone; the difference between AHLM and AHORF25400^m is -19 mm; the shape of the HORF25400 graph is considerably distorted for the coarse single-axis load-cell wall.

In the FWRB NCAP crash test reports [1], it is in general not easy to see the additional load paths in the front-end structure of the car such as SEAS and subframes since only the pictures of underbody view are given. In many vehicles, the underbody is covered obstructing the view. Besides, there is no information on the strength of these additional load path structures. This lack of information can make some interpretations difficult.

SUV, LT and Van have lower standard deviations for the HORF25400 values in comparison to the passenger cars; but it is not possible to say exactly that these vehicles have SEAS. SUV, LT and Van have their AHORF25400^m values out of the Part 581 bumper regulation zone, thus they have a risk of overriding lower vehicles. The higher standard deviation values can also be caused by the noise in the early stages of crash around 25 mm of deformation which can cause much higher and much lower HORF25400 values than normal as described in Section 3. As expected, standard deviations are lower for the coarse load-cell matrix (except the light-truck LT) since the use of such load-cell matrices have an averaging effect of the crush forces. It can be said that it is favourable to have lower standard deviations for HORF25400 values while having good force homogeneity so as to mitigate excessive bending of structural members and to provide good structural interaction.

It is observed that AHORF25400^s values are very close to AHORF25400^m considering the fact that maximum true error is -7.8 mm while in general the true error is around $\pm$ 2 mm. However, the use of coarse single-axis load-cell matrix produces considerable error (upto 35 mm) in the value of AHORF25400. Besides, in comparison to the true variation of height of resultant force given by AHORF25400^m, the variation of HORF25400 for the coarse single-axis load-cell matrix is very distorted in general. No relationship has been found between AHORF25400^m and the type of engine placement given in Table 1. AHORF25400^m values are in general lower than the average height of longitudinal member (AHLM) except for the vehicles PC3 and Van. Considering the recent vehicles in this study, a correlation between AHORF25400^m and longitudinal member top height (LMTH) is seen as shown in Fig. 11 indicating that vehicles with higher longitudinal members have higher AHORF25400 values; an explanation for this is that longitudinal members are designed to be the primary energy absorbing structures (PEAS). Such a correlation is found in other studies as well [6, 12].

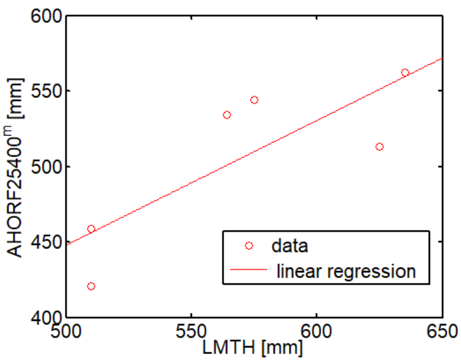


Fig. 11 Correlation between AHORF25400^m and longitudinal member top height (LMTH)

6. Conclusions

This study presents an investigation of the effects of load cell wall design on the value of average height of resultant force value (AHORF25400) in the first 25 mm to 400 mm of crush obtained in FWRB NCAP crash tests. AHORF25400

is an important parameter to estimate the risk of override/underride frontal crashes but does not ensure good structural interaction (or convergence) since it is possible that similar AHORF25400 values can be obtained with different force distributions at the front-end of the vehicle and the existence or nonexistence of additional load paths may yield similar AHORF24500 values [6, 8, 9].

In order to calculate AHORF25400 for different types of load cell walls, Matlab algorithms were written that automatically read and export the experimental data, filter raw data from load cells and accelerometers, create coarse load-cell matrix and make kinematic analyses of the crashes. This paper involves the analyses of most recent crash tests thus it is a contribution to the previous studies [5]. It is observed that rigid walls with 125 × 125 mm single-axis load cells provide much more accurate AHORF25400 values in comparison to rigid walls with 250 × 250 mm single-axis load cells since the single-axis coarse load-cell matrix produces errors up to 37mm which is a significant portion of the Part 581 bumper regulation zone. When single-axis 125 × 125 mm load cells are compared to multi-axis 125 × 125 mm load cells, it appeared that the inclusion of moments did not change AHORF25400 values considerably since the errors were around 2 mm in general with maximum error being at most 7.8 mm; this observation is in accordance with the results of a previous study [5]. HORF25400 variations are very similar for single-axis 125 × 125 mm load cell walls and multi-axis 125 × 125 mm load cells; therefore single-axis 125 × 125 mm load cell walls provide enough accuracy to calculate AHORF25400 and they are also cost-effective compared to multi-axis load cell walls. Hence, AHORF25400 values obtained from older crash tests in which single-axis 125 × 125 mm load cells were used, can be reliably compared with the AHORF25400 values of recent vehicles which are calculated using multi-axis load cells.

References

1. National Highway Traffic Safety Administration (NHTSA) [online cit.: 2018-06-03]. Available from: www.nhtsa.gov
2. **Mohan, P.; Marzougui, D.; Kan, C.-D.** 2007. Modified Approach to Accurately Measure Height of Force (HOF). 2007 SAE World Congress, Detroit, Michigan, SAE paper 2007-01-1182.
3. **Fujii, S.; Sunakawa, T.; Abe, A.; Fukushima, M.; Kawaguchi, K.; Ogawa, S.** 2004. Aggressivity-Reducing Structure for Large Vehicles in Frontal Car-to-Car Crash. 2004 SAE World Congress, Detroit, Michigan, SAE paper 2004-01-1163.
4. **Barbat, S.; Li, X.; Reagan, S.; Prasad, P.** 2007. Vehicle Compatibility Assessment Using Test Data of Full Frontal Vehicle-To-Vehicle and Vehicle-To-Full Width Deformable Barrier Impacts. Proceedings of the 20th ESV Conference, Lyon, France, National Highway Traffic Safety Administration, paper 07-0348.
5. **Brewer, J.; Patel, S.; Summers, S.; Prasad, A; Mohan, P.** 2011. Accuracy of AHOF400 with a Moment-Measuring Load Cell Barrier. Proceedings of the 22nd ESV Conference, Washington D.C., USA, National Highway Traffic Safety Administration, paper 11-0335.
6. **Mizuno, K.; Arai, Y.; Notsu, M.** 2005. Full-Width Test and Overload Test to Evaluate Compatibility. 2005 SAE World Congress, Detroit, Michigan, SAE paper 2005-01-1373.
7. **Stein, M.; Johannsen, H.; Thomson, R.** 2013. FIMCAR – Influence of SEAS on Frontal Impact Compatibility. Proceedings of the 23rd ESV Conference, Seoul, South Korea, National Highway Traffic Safety Administration, paper 13-0436.
8. **Haenchen, D.; Schwarz, T.; Thomas, G.; Zobel, R.** 2004. Feasible Steps towards Improved Crash Compatibility. 2004 SAE World Congress, Detroit, Michigan, SAE paper 2004-01-1167.
9. **Takizawa, S.; Higuchi, E.; Iwabe, T.; Sugimoto, T.; Kisai, T.; Suzuki, T.** 2004. Experimental Evaluation of Test Procedures for Frontal Collision Compatibility. 2004 SAE World Congress, Detroit, Michigan, SAE paper 2004-01-1162.
10. Society of Automotive Engineers (SAE). 2007. SAE J211-1 (1995): Instrumentation for Impact Test, Part 1, Electronic Instrumentation.
11. Messring Systembau MSG GmbH [online cit.: 2018-03-07]. Available from: www.messring.de
12. **Verma, M.K.; Nagappala, R.; Tung, Y.J.; Zimmerman, M.R.; Murugan, M.; Bernstein, T.A.** 2004. Significant Factors in Height of Force Measurements for Vehicle Collision Compatibility. 2004 SAE World Congress, Detroit, Michigan, SAE paper 2004-01-1165.

Characteristics and Assessment of the Road Safety Level in Poland with Multiple Regression Model

A. Świderski [1], A. Borucka[2], P. Skoczyński[3]

[1]*Motor Transport Institute, Jagiellońska 80 Str, 03-301, Warsaw, Poland, E-mail: andrzej.swiderski@its.waw.pl*
[2]*Military University of Technology, Urbanowicza 2 Str, 01-476, Warsaw, Poland, E-mail: anna.borucka@wat.edu.pl*
[3]*Motor Transport Institute, Jagiellońska 80 Str, 03-301, Warsaw, Poland, E-mail: przemyslaw.skoczynski@its.waw.pl*

Abstract

Road safety is a very complex issue, conditioned by many elements. These include individual predispositions of traffic participants, technical condition of transport infrastructure and means of transport, as well as external, independent causes that are not shaped by the man, such as weather conditions, time of the day, day of the week or month. The article presents a general analysis of accidents in Poland, taking into account selected factors that affect their occurrence, as well as the number of victims. The multiple regression model was proposed for their mathematical description and prediction of future events. Such a model will enable to identify periods requiring increased activity of operational services, while at the same time emphasizing the need for increased vigilance and caution of all traffic participants, which may directly affect the level of safety in road traffic.
KEY WORDS: *road safety, road traffic accidents, forecasting, multiple regression model*

1. Introduction

Thousands of victims die in accidents every year. Last year, as many as 2.831 people died in 32.000 accidents in Poland and more than 39.000 were injured [4]. Undoubtedly, every measure that contributes to improve road safety is very important and can be an opportunity to protect human life and health. The implementation, organization and popularization of activities in the informational, legislative and preventive aspect is extremely important, as well as development of research and monitoring areas for the condition, changes and effects of road events. One of the bodies supporting such activities is the Polish Road Safety Observatory (POBR), which operates at the Motor Transport Institute. One of its statutory objectives is to collect data on risks on the Polish roads. In this article, on the basis of such information, the characteristics and assessment of road safety level in Poland have been carried out in terms of selected factors. An aim was not only to provide a mathematical representation and prediction of the analyzed phenomena, but also to disseminate knowledge on safety and to increase the awareness of road traffic participants.

2. Research Subject

The analysis covered accidents recorded in 2013-2017 in the whole country. Preliminary studies show that, on average, there were 93 fatal accidents every day in which 8 persons died, with 113 serious injuries and 31 serious injuries [4]. So many victims are killed on Polish roads every day, which undoubtedly shows the scale and importance of this problem. A graphical illustration of the number of accidents over the whole analyzed period that led to further considerations is shown in Fig. 1.

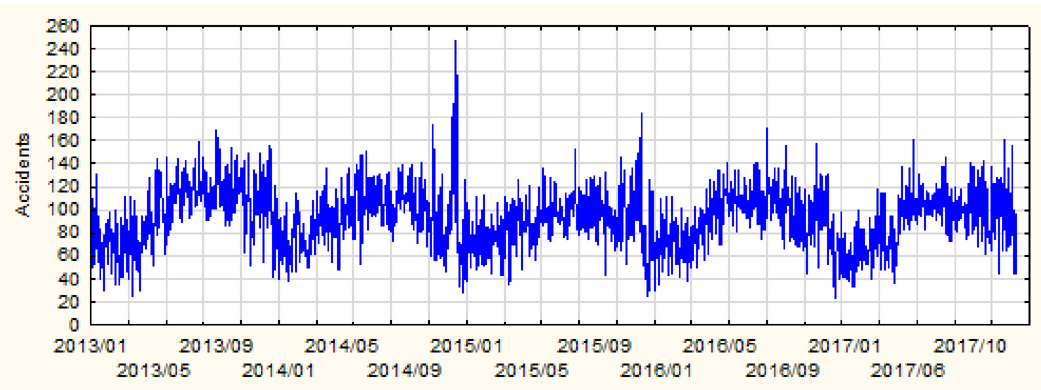


Fig. 1 Number of accidents on Polish roads in 2013-2017

The above chart clearly shows the outlier observations. Their existence is also confirmed by the box plot below in

Fig. 2 and by conducted Grubbs test for which the value of test statistics was 6.01 at the significance level of α=0.05 and was higher than the critical value. Therefore, there was no reason to accept the H0 hypothesis that the minimum value of x_{max} and minimum value of x_{min} were part of results distribution [3].

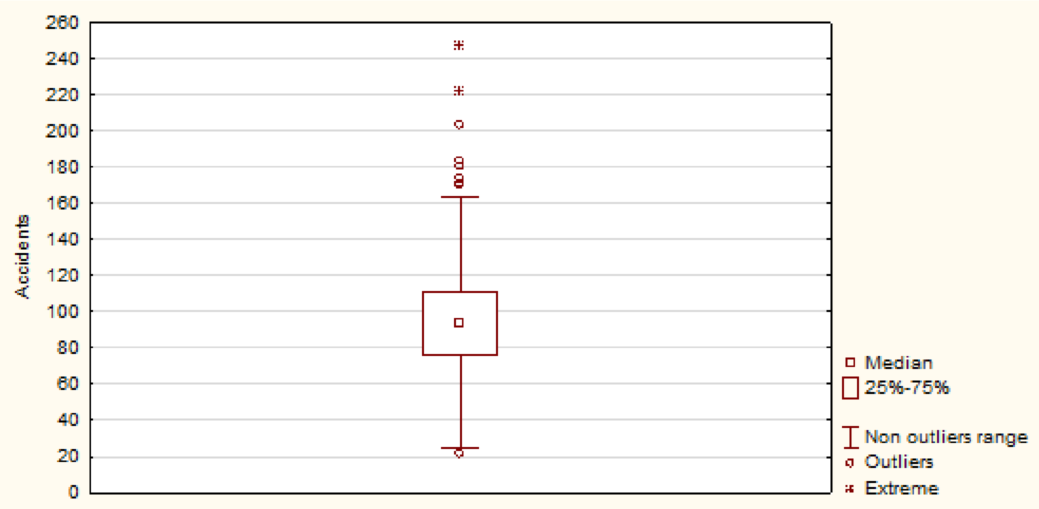


Fig. 2 Box plot of accidents in analyzed period

A closer analysis of outlier observations has shown the sad truth that they relate primarily to the Christmas period. Most accidents occur on days when people go to their family and friends, just before Christmas Eve. The highest recorded value concerned 19.12.2014, when there were as many as 248 accidents in which 23 people died and 264 were injured. A year earlier at this time on 20.12.2013 there were 156 accidents, similarly in the following years: 21.12.2015 – 184 accidents, 22.12.2016 – 127 accidents. All these values are far from average and may therefore hamper proper process analysis and exert excessive pressure on regression results. Although the presented abnormality does not result from measurement error, but their inclusion in the data set may cause significant changes in regression coefficients. The outliers were replaced with expected values, but due to seasonality of the process related to weekly and monthly variability, the average for specific weekdays in individual months was used. In this way, a database for further analysis was obtained. The diagram of analyzed variable is presented in Fig. 3, and the basic descriptive statistics are presented in Table 1, which reduced the coefficient of variation by about 11%, but still remained at the level of 24%, which results from the high seasonality of presented data.

Table 1

Basic descriptive statistics of the process without untypical observation

Variable	Basic descriptive statistics						
	Count (N)	Mean	Median	Minimum	Maximum	Standard deviation	Coefficient of variation
Accidents	1755	93.03	94	43	143	22.74	24.44

The aforementioned seasonality of process, clearly visible in Fig. 3, refers to variability resulting from the weekday and from the month.

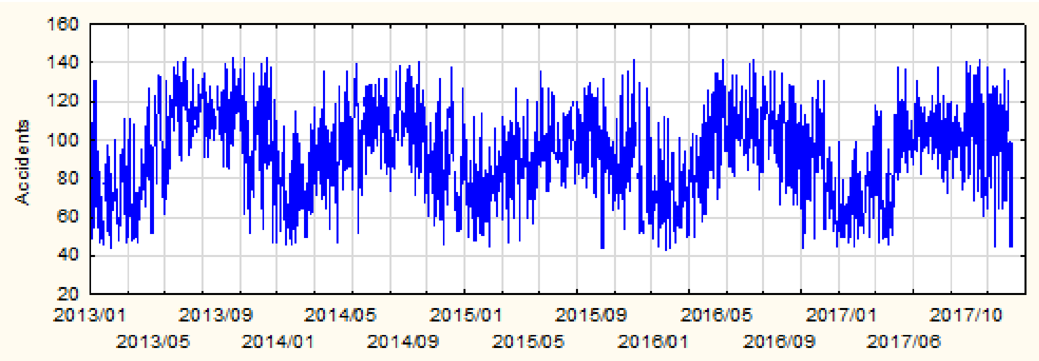


Fig. 3 Number of accidents in 2013-2017 without untypical observations

It turns out that most accidents are on Fridays (Fig. 4), which probably results from the fact that it is often a departure day before the upcoming weekend. Unexpectedly low is the average on Sundays, when returns seem to be taking

place, but it is the safest day of the week. A high average on Mondays, as the second highest, is an explanation indicating that this is the day more often chosen for returns. This is probably due to commuting to work, which is associated with significant migration of people for economic purposes from nearby towns to large cities.

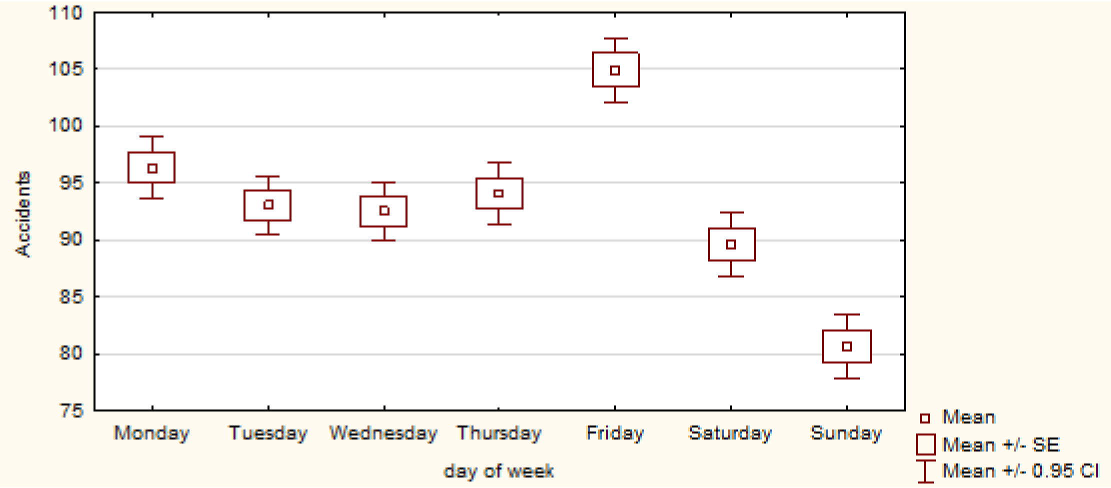


Fig. 4 Diagram of the number of accidents in weekdays

However, the monthly seasonality indicates (Fig. 5) that the most dangerous is holiday period, when holiday trips take place. This unsafe time begins in June and lasts until October. A significant accident is also reported in May, which is related to celebration of the long May weekend and December, which is influenced by the already mentioned Christmas trips.

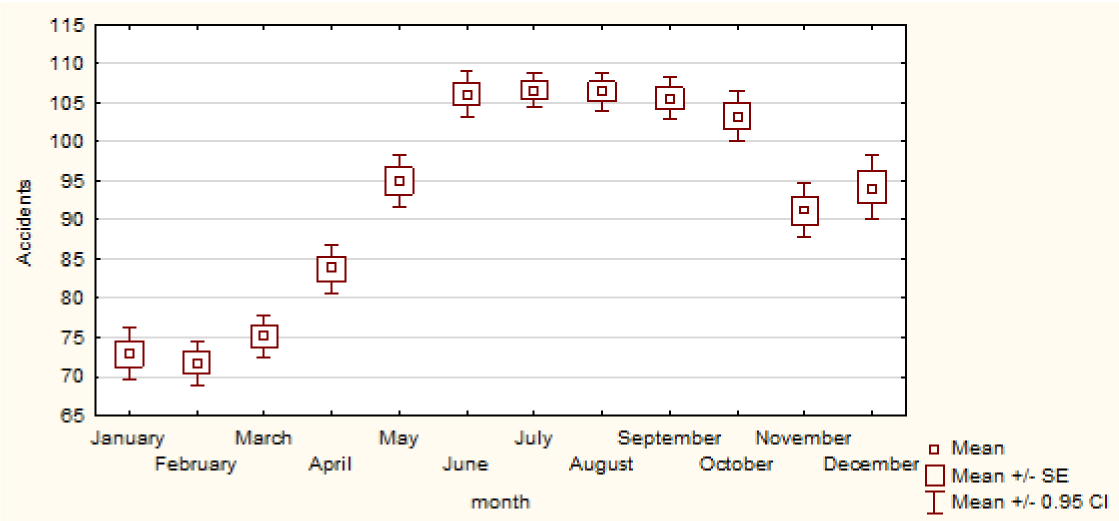


Fig. 5 Diagram of the number of accidents in individual months

3. Research Methodology

One of the cause-effect models, i.e. multiple regression, was proposed in order to take into account all the interrelations that occurred in studied phenomenon. Its aim is to describe properly, quantitatively, the relations that occur between many independent (explanatory) variables and a dependent (explained) variable. It allows for evaluation and mathematical description of the strength and direction of occurring relations, and for prediction of one variable based on values observation of other variables that are correlated with it. Multiple regression is an extension of the simple regression model and takes the form of (1) [1, 2, 3]:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon 17 \tag{1}$$

Correct analysis and classification of variables is very important in construction of the regression model. In analyzed case, we are dealing with qualitative variables, i.e. weekdays and months, which do not have any economic sense, and therefore complicate the estimation process and require special measures. They have to be converted into dummy variables indicating individual seasonal variations, and the model thus defined enables to use the method of least squares, because there will be a linear relation between regressors. The dummy variables will be added to the unit vector for each

of observations in the sample, which will cause X matrix peculiar and X'X inverse matrix will not exist. Therefore, X matrix should be corrected by subtracting one of the binary variables from the set and estimating the “reduced” model [3]. This variable will be a reference level for others in the set. Since in the analyzed situation, the strong weekly seasonality is imposed by equally important monthly seasonality, it was necessary in the model to take into account two groups of factors responsible for the above mentioned impacts. One variable had to be eliminated for each of them. In the first group, the one corresponding to Sunday was removed, and in the second group in April, and such a model was estimated, obtaining the following values of parameters, for better visualization, presented in the following two tables (Table 2 and Table 3).

Table 2

Values of regression parameters for weekdays

Variable	const	Monday	Tuesday	Wednes-	Thursday	Friday	Saturday
Parameter	71.75	15.19	11.92	11.52	12.99	25.19	8.51
SD	1.73	1.51	1.51	1.51	1.51	1.51	1.51
V%	2.4	9.97	12.69	13.13	11.64	6	17.76

Table 3

Values of regression parameters for months

Variable	Jan-	February	March	May	June	July	August	September	October	November	December
Parameter	-	-11.75	-8.15	11.22	22.47	22.85	23.02	21.57	19.42	7.97	11.08
SD	1.98	2.03	1.98	1.98	1.99	1.98	1.98	1.99	1.98	1.99	1.98
V%	-	-17.25	-24.28	17.64	8.88	8.66	8.6	9.25	10.19	25.02	17.86

All parameter values are statistically significant, which is highly satisfactory information, especially due to the easiness of model interpretation. The corrected determination coefficient R^2 is 42%, which means that the independent variables taken into account explain more than 40% of the relations that occur in the model, which should also be considered as a satisfactory result, because road accidents are influenced by many factors, often difficult to predict, such as individual predispositions of the driver or weather. High value of test statistics $F(17.1808) = 76.014$, which is a study of total significance of regression coefficients and corresponding probability level $p < 0.0000$ confirm that the estimated model is statistically significant. The standard estimation error informing about the “fitting” level of model to the empirical data is $Se = 17.274$, which means that the empirical values of the rate on the number of accidents in a given calendar day deviate on average from theoretical values by about 17 accidents, which in the analyzed process can be considered as an acceptable level. The last verification stage of the estimated model is analysis of residues distribution. In a properly constructed model, it should have a distribution close to normal and the random element ε should have an expected value of zero. The residues distribution histogram shown in Fig. 6 and the calculated empirical statistics of Kolmogorov – Smirnov, Lilliefors and Shapiro-Wilk tests confirm the normal distribution, while calculated average value of residues is equal to 0.

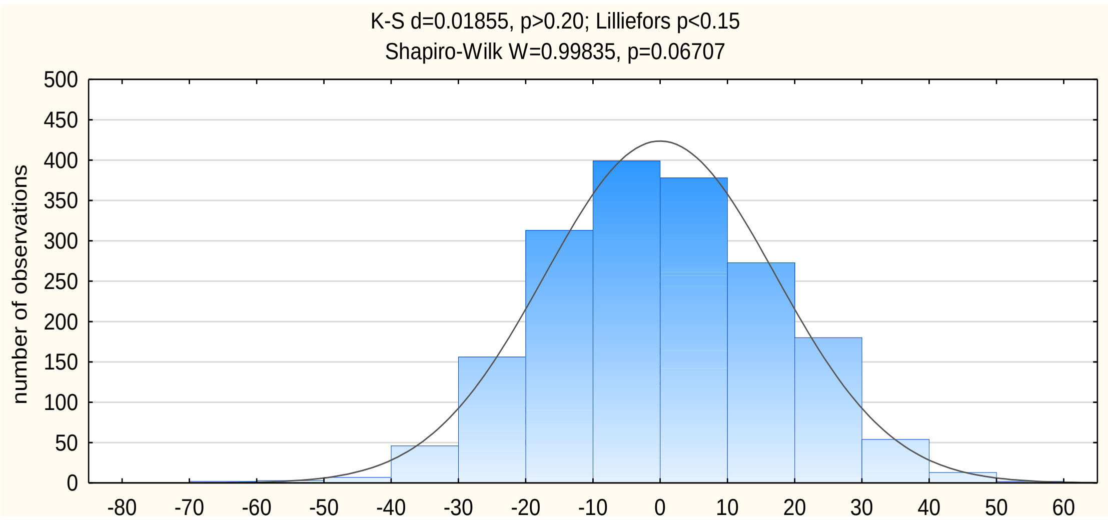


Fig. 6 Histogram of residuals distribution

Therefore, estimated model can be considered to be the correct one. The diagram of empirical and forecasted values presented in Fig. 7 shows that it effectively follows the series and well reflects the seasonality of process, but it does not fully deal with deviations, as it is not able to describe both high and low indications satisfactorily. This may be due to the abovementioned effects of factors not taken into account in the model, which affect the value of individual observations.

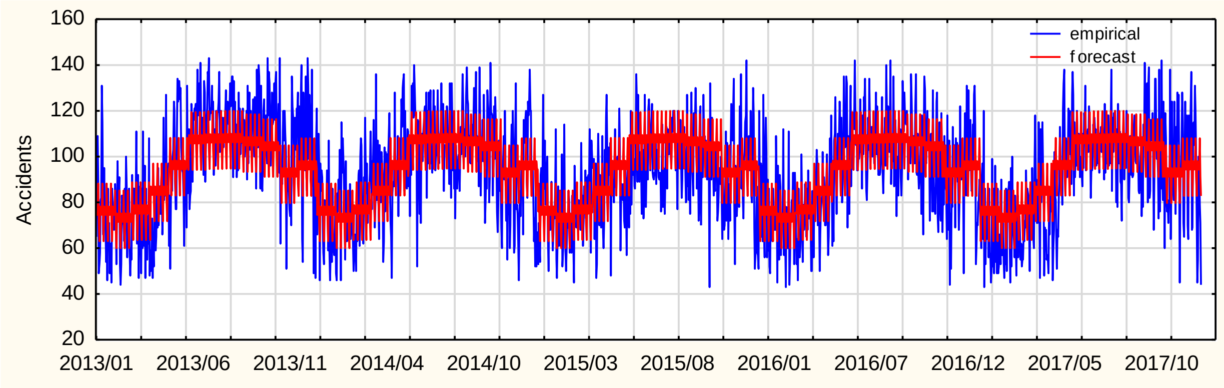


Fig. 7 Diagram of empirical values and predicted with regression model

4. Results Analysis

In order to see the effectiveness of prediction with regard to developed model, observations from the beginning of 2018 were used. In Table 4 the obtained forecast is compared with empirical values from the first days of January, along with calculated forecast errors. The highest value of error concerned 1.01.2018, for which the forecast is heavily overestimated. However, this is due to the fact that this day is a holiday: New Year, the day after New Year's Eve, when traffic on the roads is low and most people rest after the party is over, and the proposed model does not take into account public holidays.

Table 4

Comparison of forecasts and empirical test values

Date	Day of the week	Forecast regression model	Empirical data	Mean standard error Ψ [%]
2018-01-01	Tuesday	74.95	45	-66.56
2018-01-02	Wednesday	74.55	84	11.25
2018-01-03	Thursday	76.02	106	28.28
2018-01-04	Friday	88.22	66	-33.67
2018-01-05	Saturday	71.55	108	33.75
2018-01-06	Sunday	63.03	43	-46.59
2018-01-07	Monday	78.22	49	-59.63
2018-01-08	Tuesday	74.95	74	-1.28
2018-01-09	Wednesday	74.55	76	1.91
2018-01-10	Thursday	76.02	77	1.27
2018-01-11	Friday	88.22	90	1.97
2018-01-12	Saturday	71.55	73	1.99
2018-01-13	Sunday	63.03	56	-12.56

The whole first week of January is characterized by certain specificity, as it is a period in which many people take their leaves, prolonging their holidays, and therefore the estimated forecasts may be misleading. This model works much better in the second week, when the traffic situation returns to its natural rhythm. Then most forecasts almost exactly hit the point. The average forecast error for the first week is 36%, while for the second it is only 11%. Nevertheless, for the whole test period it amounts to 23%, which makes it possible to consider the model satisfactory. The diagram of empirical values, including test values, is presented along with a forecast in Fig. 8.

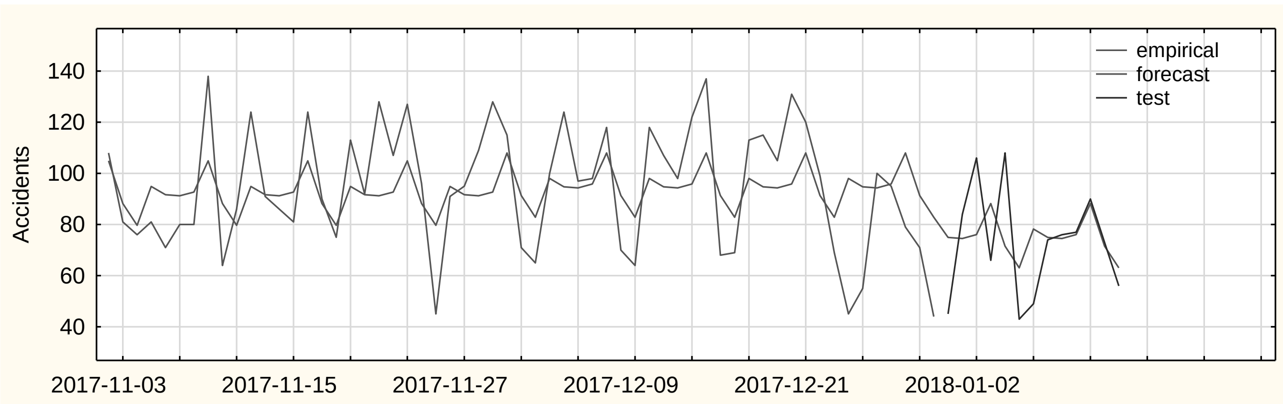


Fig. 8 Diagram of empirical, test and predicted values

5. Conclusions

Reality is usually very complex and is influenced by many factors, not always possible to describe mathematically. However, the assessment of quantitative relations between different aspects of the analyzed processes may enable their better understanding, predicting their development with a certain probability, as well as to use for further research and simulation, and in the analyzed case also to take preventive measures. Information on the expected increase in the number of accidents is valuable news for drivers, which can affect their concentration and increased vigilance and caution on the road. Such forecasts are also an important indication for systems responsible in maintaining public safety and order, as well as for rescue purposes. As a result, the number of accidents and their victims will not only decrease, but also the awareness and caution of traffic participants will increase.

References

1. **Dittmann, P.; Szabela-Pasierbińska, E.; Dittmann, I.; Szpulak, A.** 2011. Forecasting in sales and financial management of a business. Warsaw: Wolters Kluwer Polska Sp. Z o.o.
2. **Rabiej, A**. 2012. Statistics with the Statistica program. Gliwice: Helion Publishing House.
3. StatSoft. 2006. Electronic Manual of PL Statistics, Cracow [online cit.: 2018-05-22]. Available from: http://www.statsoft.pl/textbook/stathome.html
4. Data on accidents collected and made available by the Polish Road Safety Observatory

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Land Warrior System Estimation: Case of Lithuania Troops

S. Bekesiene

Military Academy of Lithuania, EMD, Šilo 5A, 44239, Vilnius, Lithuania, E-mail: svajone.bekesiene@lka.lt

Abstract

Nowadays advances in technology have increased the capabilities of the potential of individual soldiers to function as shooters, sensors, and communicators. Today the warrior is seen as a live weapons platform, also as a source of battlefield intelligence and a vital link in command and control communications This paper follows the army operating concept, which highlights the importance of ready land forces' for protecting nation and securing of vital interests against more and more capable enemies.

The overall purpose of the work is to contribute to the individual soldier as the army's vital weapon. The current paper deals with the future Lithuanian Land Warrior system and its effectiveness in the context of other NATO alliance countries. For this research, the experts' evaluation methods based on experts' surveyed sample analysis were conducted. In addition the hierarchical clustering analysis was chosen to evaluate the current structure and effectiveness of the Lithuanian Land Forces warrior system components: radio communication equipment, ballistic helmets, and bullet-proof vests.
KEY WORDS: *Land Force soldier's system, Kendall W, multidimensional database, hierarchical clustering*

1. Introduction

Nowadays, all countries in the world care about their security. One of the institutions that helps to maintain the territorial integrity and protects its citizens is the army. The lessons learned during wars influence the development of military equipment. All countries arm its military forces with new technology which helps the military not only to accomplish its objectives, but also to improve the quality of their performance that can be expanded by targeting capabilities: the use of radio stations, GPS receivers and unmanned aerial vehicles enabling tracking of the battle in real time from remote distance. The Land Warrior system (LWS) is also improving with more and more emerging technology-based elements on recent advances in communications, sensors, and materials that make the soldier's equipment as if he is an individual, complete weapons platform. Each subsystem and component is designed to and for the warrior. The result integrated soldier fighting system even more effective for infantryman in the battlefield during various operations (Fig. 1).

Fig. 1 British Army, French Army and Russian Army Future Soldier systems [6, 8, 19]

There are few countries which developed their own complete soldier weapon system which enabling ground forces to fight and win on the battlefields of the 21st century. The *Ratnik* is a Russian infantry combat system, the *FELIN* is a French Future Soldier System, the *IdZ* (Infanterist der Zukunft) is the Future Soldier System (FSS) of Germany, the *Dominator* (Elbit systems) is an Israel FSS, the *Land Warrior* is the the U.S. Army FSS [3-7, 13, 16, 19].

There are few priorities in FSS: lethality, survivability, command and control. Following by these priorities the U.S. Army Land Warrior system is developed as the high-tech equipment with several subsystems [22]:

- the weapon subsystem, which includes key electrical optical components: video camera, and the laser rangefinder/digital compass (LRF/DC). This system will allow infantrymen to operate in all types of weather and at night.

In conjunction with other components, a soldier can even shoot around corners without exposing himself to enemy fire;

- the integrated helmet assembly subsystem uses advanced materials to provide ballistic protection at less weight than the current helmet shell;
- the protective clothing and individual equipment subsystem consists of a revolutionary backpack frame design based on state-of-the-art automotive racing technology which bends with the soldier's natural body movements;
- the infantryman will attach the Computer/Radio Subsystem (CRS) to his load-bearing frame;
- the CRS is integrated into the backpack frame in two sections. This gives the soldier the ability to communicate with others in his squad, greatly improving situation awareness and survivability through increased command and control;
- the lower portion of the backpack contains the computer and the global positioning system (GPS) modules;
- the Land Warrior software subsystem addresses the soldier's core battlefield functions, display management, and mission equipment and supply.

The Russian Defense Ministry decided to start the mass purchases of Russian-made designed future soldier gear Ratnik in 2014. Now more than 80,000 soldiers in the Russian army are equipped with the Ratnik-2. Russian-made FSS gear Ratnik, comprises more than 40 components, including firearms, body armor and optical, communication and navigation devices, as well as life support and power supply systems, and even knee and elbow pads. The equipment can be used by regular infantry, rocket launcher operators, machine gunners, drivers and scouts. In 2016 September, Russia has started the development of the third generation Ratnik infantry combat system. In the third generation combat soldier equipment Russia are planning to integrate various biomechanical tools, including exoskeletons [19].

The future infantry soldier equipment used by the French Army is FELIN (Fantassin à Équipements et Liaisons Intégrés). The FELIN system project was led by the French Company Sagem in partnership with several French defense companies. The latest generation of FELIN system is based on a modular concept and is compatible with all combat operations (day, night, dismounted, mounted on vehicles and aircraft, airborne, in urban, rural or wilderness areas) [8].

The Lithuanian Defense Ministry understands, that Lithuanian Land Force (LLF), which is one of the four Armed Forces of Lithuania under the Chief of Defence and is responsible for the defence and security of the land territory of the Republic of Lithuania, forms the backbone of the country's defence force. For this purpose, the Lithuanian Defense Ministry made the decision to optimize the Lithuanian Land Forces soldier system, so that there would be no large corrections in supplement, the surplus production or unnecessary inventory, and that the existing parts of the soldier system would ensure its safety. The direction of these intentions are also specified in the 2015-2020 year guidelines (Minister of National Defence in 2015. January 27. Order No. V-82) by the Lithuanian Minister of National Defence . In the near future particular attention will be paid to the Lithuanian Land Force, because the use of military equipment in Navy or Air Forces is much more influenced by armaments and military equipment (e.g. aircrafts, ships). The Lithuania is one of NATO members and the Lithuanian Armed Forces participated in the international military missions and operations in Afghanistan, Iraq, Kosovo and Bosnia. This experience shoved that it is important each soldier and let to make the decision to improve the individual soldier's equipment, armament, and outfit designed for soldiers to be comfortable, practical, and easy to use.

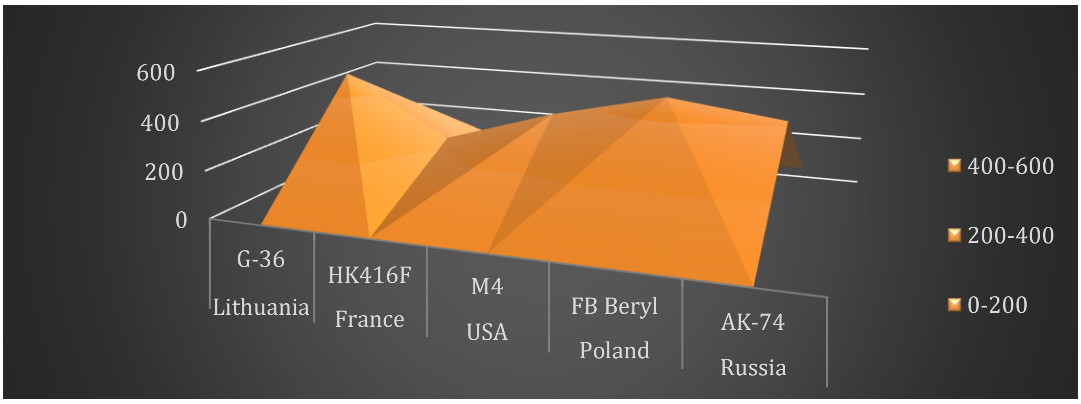
The Ministry of National Defense of Lithuania defines several requirements and expectations for future Lithuanian Army Warrior System capability. However, the scientific literature does not analyses the Lithuanian Land Force soldiers system, for this reason it is particularly relevant to evaluate the current structure of the Land Forces soldiers system and its effectiveness in the context of other NATO alliance countries. This paper investigates the Lithuanian Land Force Soldier system optimization, for its intended purposes, technical characteristics and individual components [3-7, 18].

2. Lithuanian Land Force Soldiers System Analysis in the Context of other Countries

As was already mentioned, the Lithuanian Land Force soldier's system and sub-systems elements isn't strictly defined. For this reason, the Lithuanian Army Warrior System (LAWS) can be regarded as all that the soldier has during his tasks. In point of this view in this research the LAWS for infantryman was divided into eight main elements, where each of them has its own subsystems:

- Ballistic protection (helmet; bulletproof vest; glasses);
- Radio communication (radio stations: L-3501; Motorola and Harris);
- Optical instruments (night vision devices; thermo visor; binoculars; optical scope; collimator targeted);
- Armament (automatic rifle G-36; pistol GLOCK);
- Ammunition system (backpack with: a backup uniform, spare boots, hygiene and other; ammunition jacket with ammunition and drinking water);
- CBRB safeguards (duckling; CBRB protective suit; gloves; individual degassing agent; antidote);
- PMP measures (PMP package; medical scarf; turnstile);
- Clothing (seven-layer system; military boots; headgear).

These eight main elements at first were analyzed solely [1-4, 18, 19]. The guns analysis results are presented by the 3-D surface chart in the Fig. 2. This analysis showed that the automatic rifle Heckler & Koch G36 which is used in Lithuanian army is good quality in context of automatic rifles which are used in France and U.S. armies. The German troops also is used the Heckler & Koch G36 automatic rifle by the reason that this gun is modern and enough operational.



Source: Author's

Fig. 2 Summary of automatic rifles comparative analysis

Table 1

Warrior system evaluation by countries

Countries	Criteria				
	Ballistic protection	**C4I system**	**Power source**	**Radio communication equipment**	**Optical sights**
Lithuania	yes	NO	NO	yes	yes
France	yes	yes	yes	yes	yes
Germany	yes	yes	yes	yes	yes
Russia	yes	yes	yes	yes	yes
Israel	yes	yes	yes	yes	yes

Source: Author's

The compared warrior systems of five countries analysis clearly demonstrates that the Lithuania still does not have a C4I system and power source. Armed forces of other countries integrate modern technologies into military systems and of course they have the C4I system one of the most advanced communication support systems [4, 10, 11, 12, 21]. These results are presented in the Table 1. In order to compare and evaluate the military systems of different countries, information on the technical parameters of the elements was collected [6-8, 20]. It is important to emphasize the fact that the data on the latest technical parameters of the military system is not publicly announced, therefore only technical data that is not classified is used for this study.

3. Research Investigation Methods

For this research, the experts' evaluation methods based on experts' surveyed sample analysis were conducted, using quantitative assessments of their decisions. The investigated problem solution was the total surveyed experts' opinion. According to the experts surveyed, the average individual approach was determined by the following summaries of the expert group's opinion. The Kendall's coefficient of concordance (W) was selected for experts' data analysis. This coefficient was used as a measure of agreement among several (p) experts who were assessing a given set of n objects. Depending on the application field, the experts can be variables, characters, and so on. In the present work, they were the experts who rank parts of the Lithuanian Land Forces soldier system which, according to them, has to be optimized. Simulations were done by SPSS version 20. Following the analysis of experts' opinions, the main directions of improving the military system of the Lithuanian Land Forces were clarified: 1) technical characteristics of radio stations; 2) technical characteristics of helmets; 3) technical characteristics of bullet-proof vests.

In order to evaluate the current structure and effectiveness of the elements (radio communication equipment, ballistic helmets, and bullet-proof vests) of the military force system components of the Lithuanian Land Forces in the context of countries which belongs to NATO alliance, such as: Germany, France, USA and Poland were analyzed [1, 2, 4, 9, 10, 11, 12, 15, 17, 21]. On the basis of these data, which were additionally standardized (variable measurements were changed to z-values), the hierarchical clustering analysis was performed by the SPSS 20 software package [14].

4. Results of Analysis for Experts Data

In the present work, for the first part of research was chosen the expert method. The result of investigations in expert method depends on quality and quantity of evaluators as well. Follow recommendations the group of ten experts was questioned in this research. All of them served in the Lithuanian army approximately 17 years and have great military experience as Land force soldiers. The four of experts' are in the military service from 8 till 15 years, five of experts' – from 16 till 20 years and the one of experts' are in the military service more than 24 years. These experts have to rank a

list of presented elements and help to clarify what have to be, according to them, optimized. For this research was selected the list of 19 technical specifications for the Land Warrior system (Fig. 3): *WSE 1*- thermo-visual; *WSE 2*- longitude; *WSE 3*- glasses; *WSE 4*- military shoes; *WSE 5*- optical tuner; *WSE 6*- radio communication equipment; *WSE 7*- night vision devices; *WSE 8*- helmet system; *WSE 9*- bullet-proof vest; *WSE 10*- binoculars turnstile; *WSE 12*- collimator trick; *WSE 13*- GLOCK gun; *WSE 14*- automatic gun G-36; *WSE 15*- duckling; *WSE 16*- ammunition vest; *WSE 17*- CBRB safeguards; *WSE 18*- PMP measures; *WSE 19*- backpack. There was found the experts' opinions by the SPSS 20 package, for each of the nineteen criterions. The graphical results are shown in the Fig. 4.

Source: Author's

Fig. 3 Future Land warrior system [23]

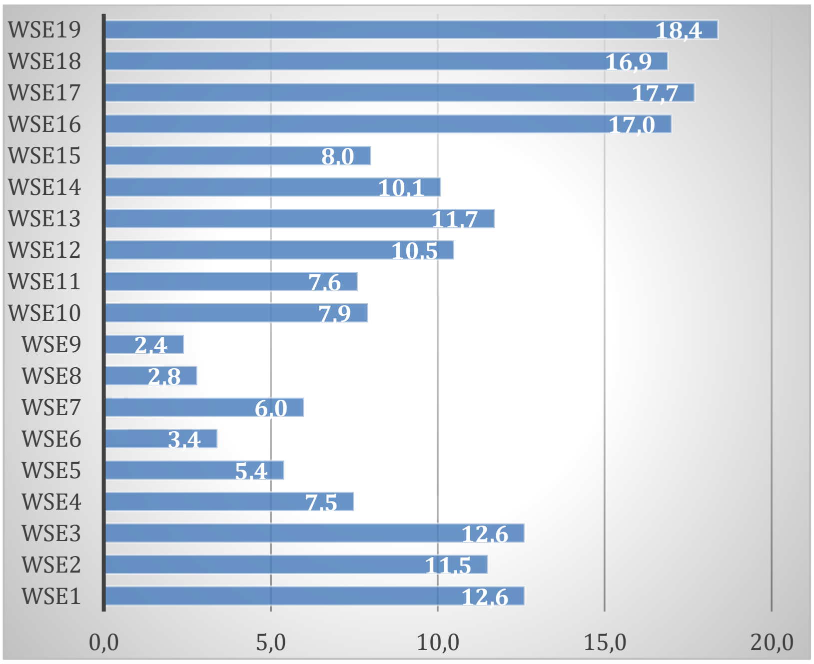


Fig. 4 Expert sample result - ranking of technical criteria

Following the analysis of experts' opinions, the main directions of improving the future military system of the Lithuanian Land Forces can be: 1) technical characteristics of radio stations; 2) technical characteristics of helmets; 3) technical characteristics of bullet-proof vests. Based on the results obtained, it can be concluded that the most important criteria (the lowest rank –the highest importance), according to experts, are: the bullet-proof vest (*WSE9* rated 2.4) and the helmet system (*WSE8* rated 2.8). Also important are criteria such as radio communication (*WSE6* rated 3.4), optical target (*WSE5* rated 5.4) and military boots (*WSE4* rated 7.5). These five criteria of significance are key to improving the system of Lithuanian Land Force troops.

5. Land Warrior System Structure Analysis Results

For this research the hierarchical clustering analysis was chosen in order to evaluate the current structure and effectiveness of the elements of the military force system of the Lithuanian Land Forces in the context of other five NATO alliance countries. There were analyzed only chosen warrior systems of Britain, Israel, USA, Poland, Germany, France and Lithuanian troops. There were used the multidimensional measurement vectors for components of warrior systems:

- *radio communication equipment* measurement vector consist of five dimensions (operating range from/till MHz, number of channels, data transfer speed Kbit/s, weight kg);
- *ballistic helmets* measurement vector consist of six dimensions (weight kg, helmet protection level according to NIJ standard, helmet thickness mm, helmet protection from bullet with speed m/s, helmet withstand a bullet shot diameter mm, helmet withstand a bullet weight g);
- *bullet-proof vests* measurement vector consist of seven dimensions (vest weight kg, vest protection level according to NIJ standard, vest thickness mm, withstand a bullet shot diameter mm, vest withstand a bullet weight g, vest body cover kg/m).

On the basis of collected data, which were before analysis additionally standardized (variable measurements were changed to z-values) there was used the agglomerative hierarchical clustering techniques, which uses the Euclidean distances or squared Euclidean distances (Eq. (1)) [23].

$$Dist(x,y) = \sum_{(m)}^{n} (x_i - y_i)^2, \tag{1}$$

where $Dist(x,y)$ – is the standard Euclidean distance (L_2) between to objects in Euclidean space; m – number of attributes.

The squared Euclidean distances measurement was used with Ward linkage method (Eq. (2)) [23].

$$d\left(U,V\right)=\left\|\bar{U}-\bar{V}\right\|^{2}\Bigg/\left(\frac{1}{n_U}+\frac{1}{n_V}\right), \tag{2}$$

where $d(U, V)$ – distance between two clusters; U – first cluster; V – second cluster.

The hierarchical clustering analysis was performed by the SPSS 20 software package [14]. get results are presented in the two tables (Tables 2 and 3) and displayed graphically by tree diagram called dendrogram (Fig. 4).

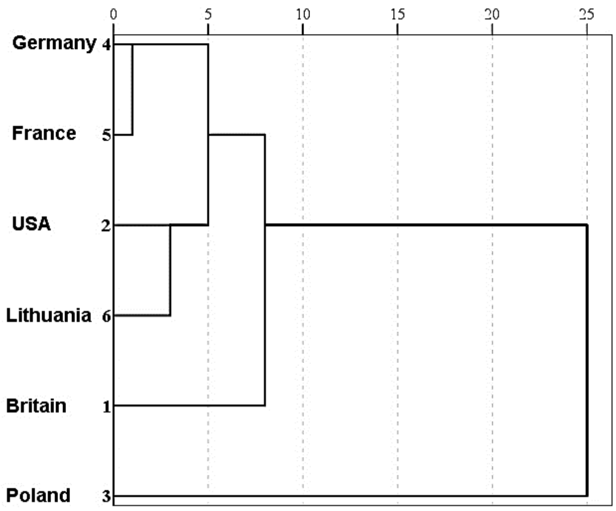
Table 2

Dissimilarity matrix for selected components of military systems for six countries

Case	**Absolute Squared Euclidean Distance**					
	1:Britain	**2:USA**	**3:Poland**	**4:Germany**	**5:France**	**6:Lithuania**
1:Britain	.000	20.282	56.856	19.454	19.182	16.898
2:USA	20.282	.000	59.613	10.530	12.478	8.486
3:Poland	56.856	59.613	.000	57.287	58.012	61.764
4:Germany	19.454	10.530	57.287	.000	.272	9.987
5:France	19.182	12.478	58.012	.272	.000	8.899
6:Lithuania	16.898	8.486	61.764	9.987	8.899	.000

Source: Author's

The hierarchical clustering analysis assisted to identify the essential differences between Land Force Warrior systems elements (Table 2). The selected elements analysis showed that the Lithuanian military system are the most different from Poland (Fig. 5).



Source: Author's

Fig. 5 Dendrogram using Ward linkage

Table 3

Agglomeration Schedule

Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	**Cluster 2**		**Cluster 1**	**Cluster 2**	
1	4	5	.136	0	0	3
2	2	6	4.379	0	0	3
3	2	4	12.663	2	1	4
4	1	2	25.294	0	3	5
5	1	3	70.000	4	0	0

Source: Author's

There are presented the agglomeration schedule in the Table 3. The merging for each country warrior system are displayed in the columns *Cluster Combined*. For the first stage there were merged 4 and 5 countries (Germany & France), for the second – 2 and 6 (USA & Lithuania) and et cetera. The column *Coefficients* in the agglomeration schedule is the within-cluster sum of squares at that step, not the distance at which clusters are joined. The columns labeled *Stage Cluster First Appears* shows at which stage each of the two clusters that are being joined first appear. At stage 3 when cluster 2 and cluster 4 are combined, you're told that cluster 2 was first formed at stage 2 and cluster 1 (known as Britain) will see action at stage 4 (information in the column "Next Stage" in the Table 3). The same information SPSS presented in graphical view (icicle plot).

6. Conclusions

From the obtained results, it can be concluded that the most appreciated parts of the system are a bullet-proof vest and backpack. This result was reached because these parts of the warrior system have been optimized very recently. In addition, the third criterion, which experts consider to be insignificant, is CBRB safeguards. Soldiers believe that CBRB's basic tools are reliable and good for use.

As we see from the study, all experts assessed the criteria *WSE16, WSE19* and *WSE17* as not significant. Therefore,

we can say that these criteria in the system of Lithuania Land Forces are not decisive in order to improve the effectiveness of the tasks performed by the soldiers.

The hierarchical cluster analysis showed that Lithuanian Land Force soldier's system components are the most similar to those used in the US army. After technical parameter data analysis, it was found that Lithuania should take into account not only the US army warrior system, but also military system tools from other countries providing land forces soldier system optimization.

References

1. Advanced combat helmet [online cit.: 2017-10-15]. Available from: https://www.military.com/equipment/advanced-combat-helmet-ach
2. AN/PRC-117G (V)1(C) type-1 wideband multiband multimission radio with internal saasm gps, Harris, [online cit.: 2017-12-14]. Available from: http://www.midkiff.cz/obj/firma_produkt_priloha_147_soubor.pdf
3. Army-Technology [online cit.: 2017-10-15]. Available from: https://www.army-technology.com/projects/fist/
4. Codan radio comunication, SENTRY-H™ SDR HF RADIO [online cit.: 2017-12-10]. Available from: https://www.codanradio.com/wp-content/uploads/Sentry-H_Datasheet_Screen_EN-Issue3-1.pdf
5. Department of defense 1997. Test method standard: V50 ballsitic test for armor. USA.
6. Elbit systems. DOMINATOR® [online cit.: 2017-11-29]. Available from: http://elbitsystems.com/media/Dominator.pdf
7. Federation of American scientists. Land warrior [online cit.: 2017-11- 20]. Available from: http://fas.org/man/dod-101/sys/land/land-warrior.htm
8. French Army to Receive FELIN Systems, (2010 m.) [online cit.: 2017-10-10]. Available from: http://www.army-technology.com/projects/felin/
9. HA-03 AIRMOBILE HELMET [online cit.: 2017-10-10]. Available from: https://www.maskpol.com.pl/en/products/ha-03-airmobile-helmet.html
10. HARRIS FALCON III® AN/PRC-152A [online cit.: 2017-12-10]. Available from: wideband-networking-handheld-radio.pdf
11. Harris RF-5000B Falcon 400W HF Radio System [online cit.: 2017-12-15]. Available from: http://www.columbiaelectronics.com/id268.htm
12. Harris RF-5800V-HH Falcon II [online cit.: 2017-12-15]. Available from: http://www.railce.com/cw/casc/harris/RF-5800V-HH.pdf
13. IdZ (Infanterist der Zukunft) Future Soldier System, Germany [online cit.: 2017-10-13]. Available from: http://www.army-technology.com/projects/idz/
14. IBM SPSS Statistics [online cit.: 2017-07-22]. Available from: http://www.ibm.com/analytics/us/en/technology/spss/
15. Improved tactical vest [online cit.: 2017-10-13]. Available from: https://www.military.com/equipment/improved-outer-tactical-vest-iotv
16. Land warrior, (2015 m.) [online cit.: 2017-10-15]. Available from: http://www.army-technology.com/projects/land_warrior/
17. Military Defense Industry Technology - Body Armour & Helmet [online cit.: 2017-10-13]. Available from: https://www.armyrecognition.com/weapons_defence_industry_military_technology_uk/russian_soldiers_will_receive_new_6b43_6b45_body_armour_and_6b47_combat_helmets_tass_12705162.html
18. NATO Standardization Agency. 2003. Stanag 2920 PPS (Edition 2) – Ballistic test method for personal armour materials and combat clothing.
19. Ratnik future soldier individual soldier combat gear system technical data sheet specifications pictures video 12205165 (2016 m.). [online cit.: 20017-12-16]. Available from: https://www.armyrecognition.com/russia_russian_military_field_equipment/ratnik_future_soldier_individual_soldier_combat_gear_system_technical_data_sheet_specifications_pictures_video_12205165.html
20. **Apariko, J.; Lovell, C.A.; Jesus T. Pastor.** (Eds). 2016. Advances in Efficiency and Productivity: International Series in Operations Research & Management Science [online cit.: 2017-10-15]. Available from: http://link.springer.com/chapter/10.1007/978-3-319-48461-7_1/fulltext.html
21. Codan radio comunication, SENTRY-H™ SDR HF RADIO [online cit.: 2017-12-10]. Available from: https://www.codanradio.com/wp-content/uploads/Sentry-H_Datasheet_Screen_EN-Issue3-1.pdf
22. Federation of American scientists. Land warrior [online cit.: 2017-11- 20]. Available from: http://fas.org/man/dod-101/sys/land/land-warrior.htm
23. Cluster Analysis Basic Concepts and Algorithms [online cit.: 2017-07-22]. Available from: https://www-users.cs.umn.edu/~kumar/dmbook/ch8.pdf

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Investigation of Ride Properties of a Rail Vehicle with Wheel Defects

J. Dižo[1], M. Blatnický[1], S. Steišūnas[2], A. Falendysh[3]

[1]*University of Žilina, Univerzitná 8215/1, 010 26, Žilina, Slovak Republic, E-mail: jan.dizo@fstroj.uniza.sk, miro-slav.blatnicky@fstroj.uniza.sk*
[2]*Vilnius Gediminas Technical University, J. Basanavičiaus g. 28, LT-03224, Vilnius, Lithuania,*
E-mail: stasys.steisunas@vgtu.lt
[3]*Ukrainian State University of Railway Transport, Feierbakh Square 7, 61050, Kharkov, Ukraine,*
E-mail: fap_hiit@ukr.net

Abstract

During rail vehicles operation it becomes, that wheel irregularities are generated on the rolling surface, which many times eventuate in serious defects on wheels. A rail vehicle running with such wheel defects is related on one hand with the defective quality of a ride comfort for passenger (in case of passenger wagons) or eventually with damage of transported goods (in case of goods wagons) and on the other hand with a ride safety and tracks damages. The profile of a defective wheel surface is no longer circular, but it gets irregular shape, which can be awfully different from original one. It comes to this that the forces ratio in wheel/rail contact can be such unfavorably changed, that the probability of the derailment risk comes to be very serious. Because of introduced reason there is necessary to investigate this phenomena in advance. Therefore the goal of this paper is to investigate, how wheel defects of a rail vehicle can affect its ride properties. Research was performed by means of computations in the multibody software in order to evaluate same important parameters characterizing dynamic properties of an investigated rail vehicle.
KEY WORDS: *rail vehicle, wheel-flat, accelerations, multibody model*

1. Introduction

The railway transport on the present still expands for transport of large number of passengers as well as large amount of freight on medium long and also long distances [17, 28]. However, this trend means also increasing number of railway vehicles making use of railway infrastructure and thereout results also greater possibility of eventual failures [9]. Despite the fact that the technical state of railway vehicles is currently indeed strict monitored and inspected [4, 18], defects on wheels surfaces can occur.

Based on found facts, we can observe several types of wheel damages. Mainly there are results of surface and subsurface fatigue, heat (thermal fatigue), further also indentations, wear, etc. Except for these types of wheel damages we know also the wheel-flat defect. This type of railway wheel profile damage is usually formed by a locked wheel sliding along the rail during braking [6], while a part of the wheel becomes flattened. The reason for this may be a defective, frozen or incorrectly tuned brake as well as a low adhesion in the wheel/rail contact surface caused by environmental condition (e. g. leaves, rain, ice, snow or combination). This defect causes high impact loads and their repetitive action may results on one hand in cracking, noise damage of railway infrastructure and on the other hand in deteriorated comfort for passenger [5]. The incidence of hot bearings, broken wheels and rail fractures are affiliated with the number of wheel-flats and out-of-round wheels [15, 16]. Operation of a rail vehicle with such a damaged wheel leads to serious defects of rail vehicles and tracks and increases the risk of train traffic safety. Due to these reasons we effort to detect and evaluate negative effects of rail vehicle running with wheel defects on a track [8].

2. Multibody Model of a Rail Vehicle

Properties of railway vehicles as a mechanical system can be designed, studied, evaluated and verified by means of experimental methods and measurements under real operation conditions or in laboratories using special equipment [7, 10, 22, 23]. Another approach based on numerical methods [13] allows to create virtual models of railway vehicle subsystems, e. g. wheelsets, bogies, etc. [26] or whole railway vehicle and even rail units and trains in specialized software [11, 12, 14], which are able to analyze running properties of them sufficiently accurate and fairly quickly.

In this contribution we present the assessment and evaluation of the influence of operation of a railway vehicle with the wheel-flat in a railway track using simulation computations. In our research we have used the Simpack multibody software.

In this software package several types of damaged wheels (wheel untrueness) is possible to model (Fig. 1). In such a case, in a wheel model the wheel circumference is not considered as purely circular. If untrueness is prescribed, then the nominal radius is no longer constant during simulation, but varies with the wheel rotation angle. Software uses for wheel/rail contact calculation a simplified method which only affects the vertical position of the wheel profile. The wheel untrueness is realized by a periodic radius change.

As we mentioned above, our research is focused on investigation of ride properties of a railway vehicle with the wheel-flat. In case of wheel-flat modeling, the radius derivation is described pointwise in polar coordinates by means of an input function with the angle ψ as the independent coordinate defined in the interval (0, 2π) and with the actual local radius $R(\psi)$ as the dependent coordinate.

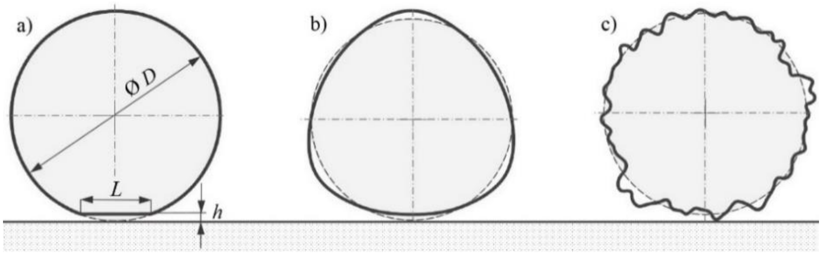


Fig.1 Options of wheel untrueness in Simpack software: a - wheel-flat; b – triangle; c - arbitrary shape

As an investigated rail vehicle the coach equipped by two two-axle bogies was chosen. The suspension of this wagon is ensured by a primary and a secondary suspension. The virtual model of a coach forms a multibody system and from the mathematical point of view it is described by the known system of the equations of motion [21, 24, 25], which general matrix formulation is given by:

$$M \cdot \ddot{u} + C \cdot \dot{u} + K \cdot u = F , \tag{1}$$

where on the left side M – mass matrix; C – damping matrix; K – stiffness matrix; $\ddot{u}$ - acceleration vector; $\dot{u}$ - velocities vector, u - displacements vector and on the right side F – loads vectors. This vector contains two main types of loads. We can express it by equation:

$$F = F_{el} + F_{cf} , \tag{2}$$

where F_{el} – vector of external loads and F_{cf} – vector of contact forces arising from wheel and rail interaction. External loads and contact forces result from specific profiles of railway wheels surface and rails, track profile, i. e. horizontal profile (curvature), superelevation ramps, track irregularities, etc. [1, 2, 27]. The multibody model of an investigated passenger wagon is shown in Fig. 2 left.

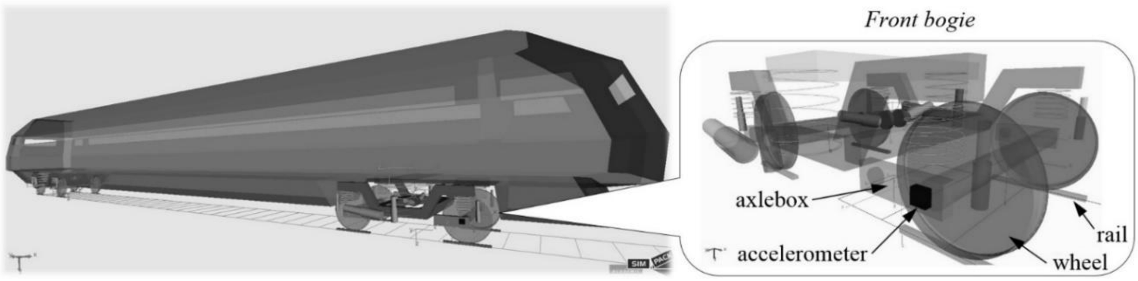


Fig. 2 Multibody model of the investigated railway vehicle (left) and detail of the location of the accelerometer on a axlebox (right)

3. Simulation Computations and Results

For our research we have used a passenger wagon model, which was run on a straight track model. The track model comprised of a one pair of rails with the common rail profile UIC60 and with the rail cant of 1:40. There were also implemented track irregularities.

We have wanted to investigate dynamic effects of the operation of a railway vehicle with the wheel-flat in our specified operation conditions, we have chosen range of speeds from 20 km/h to 160 km/h. Analyses were recorded at corresponding sampling rates depending on speeds. Moreover we have evaluated also various damage ranges by defining the typical dimensions of the wheel-flat (Fig. 1, a), i.e. the depth (h) and the resultant length (L). The depth of the flat was considered from 1 mm to 2.5 mm.

As the criteria of the investigation of ride properties of a railway vehicle we have chosen values of accelerations measured on the related axlebox (Fig. 2 left), because evaluation of acceleration values on axleboxes is one of the assessed criterion entrenched in the standard [3, 29]. We have recorded data for various speeds and flat dimensions in time. It means we have relatively large number of simulations of the passenger wagon running. Therefore, for the presentation of results we have chosen outputs in such a form, which visual illustrates monitored quantities in partial range. Furthermore, we have also statistically processed outputs of accelerations [19, 30].

In our investigation, we have evaluated dynamic effects by means of effective values of accelerations [29] individually for every direction, which are calculated in accordance with following formula:

$$a_{ef_i} = \sqrt{\lim_{T\to\infty} \frac{1}{T} \cdot \int_0^T a_i^2(t) \cdot dt}\ , \tag{3}$$

where T – maximum value of time interval; a – values of accelerations; i – index expressing direction of acceleration and it can be x, y and z depending on direction, i. e. longitudinal, lateral and vertical respectively (a_x, a_y and a_z).

Based on found results we have created cumulative graphs to show results of them for all investigated speeds and flat dimensions.

Fig. 3 shows cumulative graph of waveforms of statistically unprocessed outputs signal of accelerations in the vertical direction (z-axis) on the right axlebox of the first wheelset of the front bogie (i. e. in running direction) (Fig. 2 left). For illustration, there were selected only some results, namely for the wheel-flat depth of 1.0 mm, 2.0 mm and 2.5 mm and for the speed of 40 km/h, 100 km/h and 160 km/h. Figure is arranged in such a way: each line contains waveforms for the same wheel-flat depth and each column contains waveforms for the same running speed. Results are displayed depending on a traveled distance. For the evaluation there was chosen only relatively short track section of 50 m.

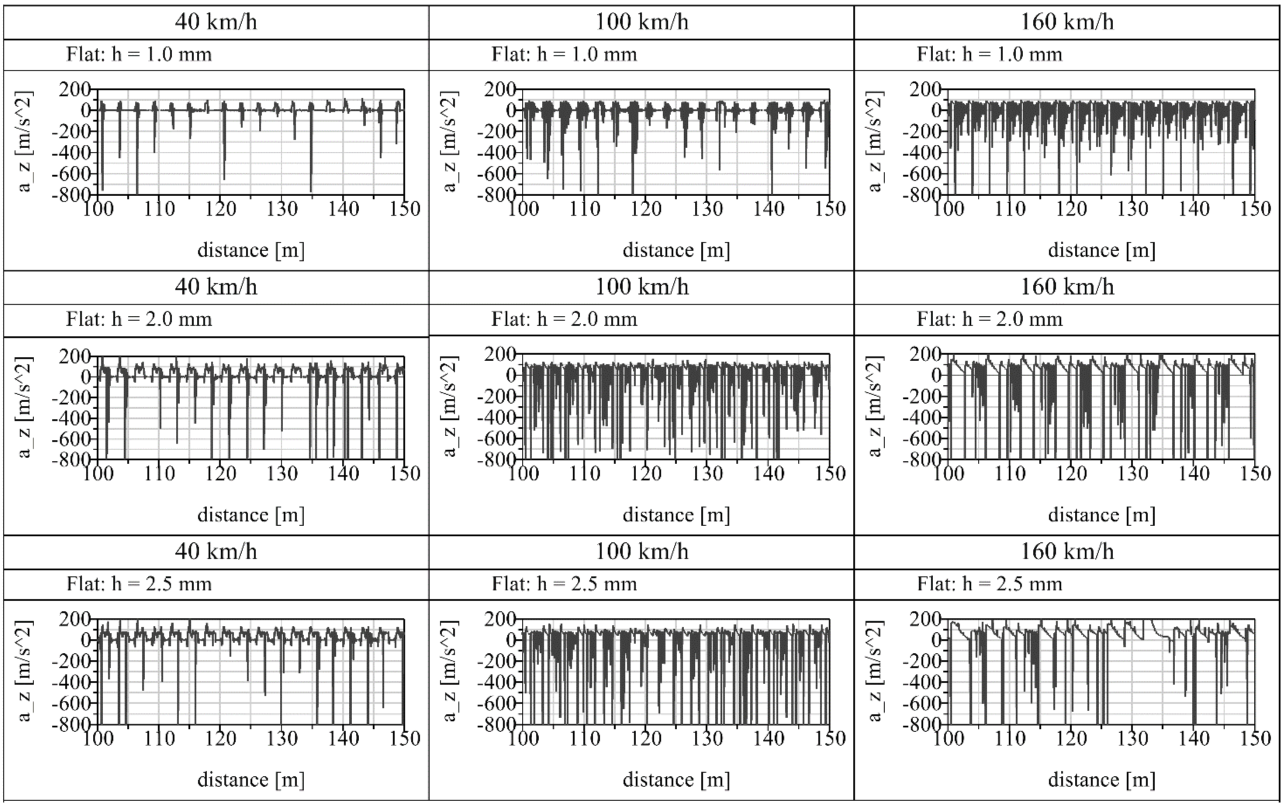


Fig. 3 Waveforms of unprocessed signal values of accelerations on the axlebox in the vertical direction (z-axis) for selected running speeds and depth of wheel-flat

From this figure we can see, that the flat on a wheel causes significant acceleration on the axlebox and thus also vibrations. Let's compare individual waveforms of accelerations. In the case of a passenger car running with the smallest wheel-flat and at the lowest speed we can see, that also accelerations are smallest. If the depth of the wheel-flat is bigger, but the speed is the same, values of accelerations do not arise such significantly. When we compare acceleration of the axlebox for the wheel-flat depth of 1.0 mm and for different speeds, we observe, that vibration of the axlebox are considerably greater.

The similar situation we can observe, when we assess other displayed results. Thus, with the deeper wheel-flat and higher speed also accelerations are increasing. But, what it is interesting, when we recognize the passenger wagon running at the highest speed and with the deeper wheel-flat, vibrations measured on the axlebox are not such significant as in the other cases. These findings are described in more detail below in connection with others graphs.

Nevertheless, identified vibration effects are very closely related to the dynamics not only with a bogie but also with a whole wagon and definitely with a track. In consideration of masses, which are connected with this oscillating part of a bogie there are arisen such vibrations, which cannot be neglected. It manifests as impacts forces causing overload of all elements of permanent way such rails, sleepers and ballast. In case of rails, there is the damage of their profiles, which

leads to significant changes in the wheel/rail contact.

By statistical processing of results of accelerations on the axlebox we have obtained effective values of accelerations in *x*, *y* and *z* directions, respectively. These outputs are entered into the spatial cumulative graph, which shows investigated results for all range of running conditions (Fig. 4). We can compare results with effective values of accelerations with results from simulation of the wagon running at various speeds, when the wheel surface is not damaged (Fig. 5).

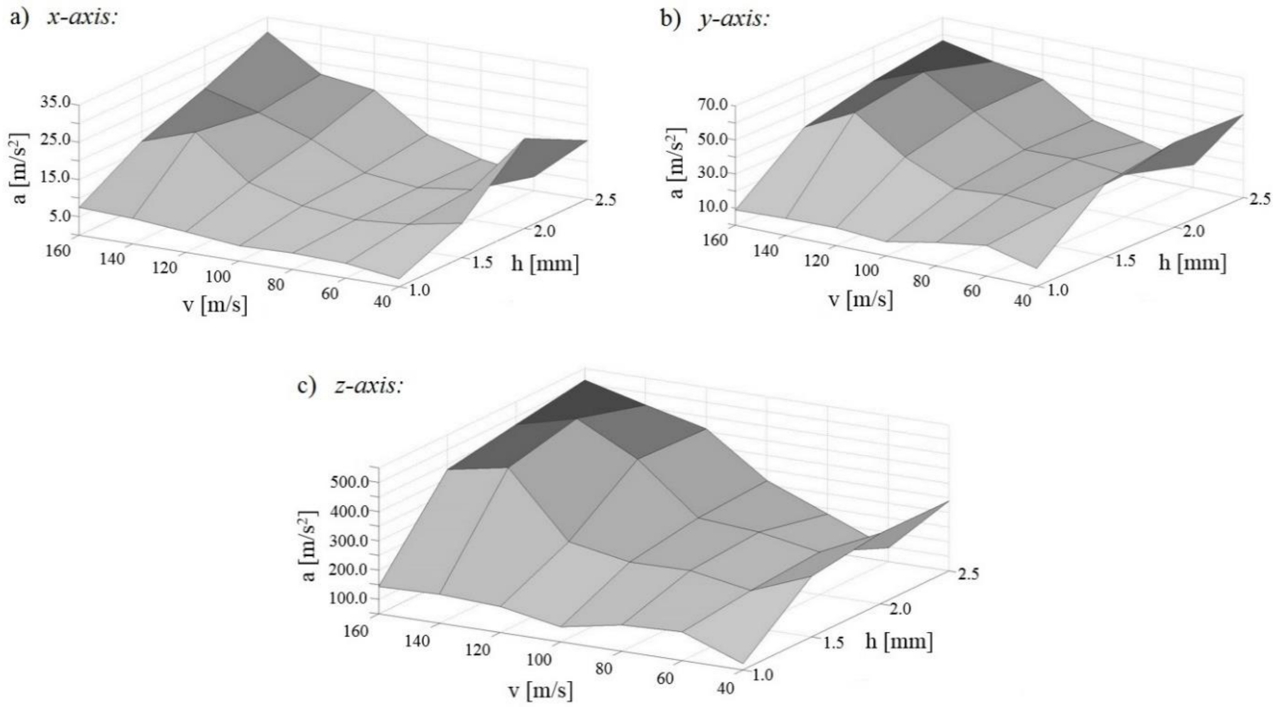


Fig. 4 Cumulative graph with accelerations for three directions: a - longitudinal direction (*x*-axis); b - lateral direction (*y*-axis); c - vertical direction (*z*-axis)

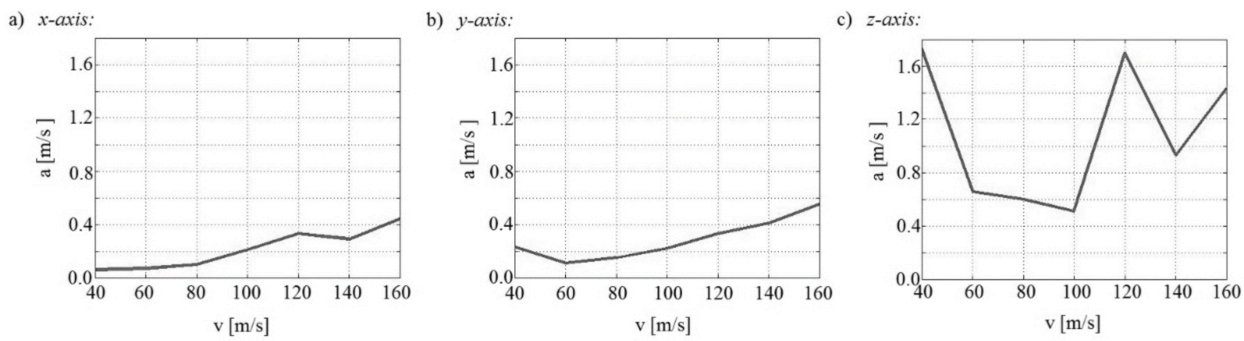


Fig. 5 Effective values of acceleration in individual directions for a wheel without any defects („perfectly“ circular wheel): a - longitudinal direction (*x*-axis); b - lateral direction (*y*-axis); c - vertical direction (*z*-axis)

Based on these results we can analyze ride properties the passenger wagon with the wheel-flat during operation. Firstly compare effective values of accelerations in individual directions. Generally we observe, the wheel-flat presence causes increasing acceleration in all three directions in comparison with wagon running without any wheel defects (Fig. XX). On closer examination we can see, that dominant accelerations arise in the vertical direction, which are higher-order compared to accelerations in the lateral direction.

Therefore, let’s focus on the assessment of results for this direction. As we would expect, increasing running speed of the wagon means increasing accelerations. The similar situation is in relation to the wheel-flat depth. The deeper flat leads to the higher acceleration. But, notice one interesting fact. When the wagon runs at relatively low speed (in our case 40 km/h), it excites greater accelerations than wagon running at higher speed. It proves the interesting phenomenon investigated and described in several works, e.g. [20]. They deal with the fact, that there is some range of speeds, in which the negative effects of a wagon running with the wheel-flat damaged wheel are utter least and for speeds greater and even smaller negative effects are worse.

This fact has the real adverse impact on the wagon dynamics. With acceleration the vertical wheel force is directly related. It means, the higher values of accelerations increase also vertical wheel forces. This results in excessive load of a track and other negative effects, which are described above.

Moreover, when we focus attention on Fig. 5, where there are displayed results from simulations of the wagon running, which any wheel is not damaged, we can see, that mechanical system of a passenger wagon oscillates much less than in previous cases. Again, the greater accelerations arise in the vertical direction (in *z*-axis), but they are incomparably smaller. These acceleration are the consequence of the wagon running on a track with irregularities.

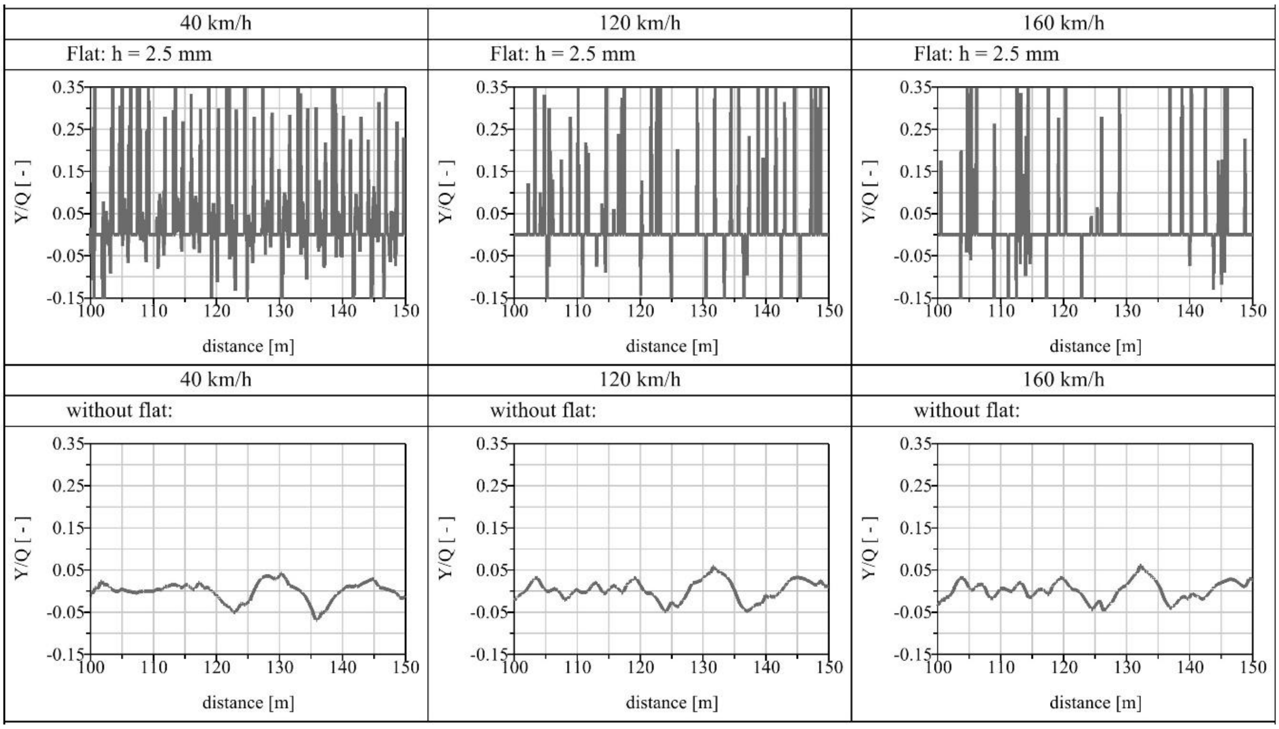


Fig. 6 Effective values of acceleration in individual directions for a wheel without any defects („perfectly“ circular wheel): a - longitudinal direction (*x*-axis); b - lateral direction (*y*-axis); c - vertical direction (*z*-axis)

Fig.6 shows results of derailment quotient waveforms for the assessment of negative effects of a wagon operation with the wheel-flat from the safety point of view. There are displayed only results for selected speed and flat depth in compliance with Fig.4. The upper part contains results for the wheel-flat depth of 2.5 mm and for speeds of 40, 120 and 160 km/h, respectively. The lower part contain waveforms of derailment quotient for the wagon without the wheel-flat. We can see, that also form the safety point of view operation of a wagon with wheel defects has negative consequences in comparison with the operation of the wagon operation with the undamaged wheel, when values of derailment are very low and oscillate about zero, which means, that the wagon running is much more safety.

To the summarize, according to our findings, railway wheel defects represent one of the most dangerous damage of railway vehicles and the operation of railway vehicle with damaged wheel causes very adverse effects as far as it is concerned to the railway vehicle deterioration and also to track damage . Simulation computations help to detect essential changes in particular regarding dynamics properties of railway vehicles. But, for more detailed simulations there is necessary to develop more detailed models of simulated structures (i. e. vehicle and track) in such a manner they would be comparable with result data from measurements in real operation or in laboratory conditions.

4. Conclusion

This article dealt with the modeling, simulation and investigation running properties of a rail vehicle which has a damaged wheel by the flat. The wheel-flat is one of the most often defect of a wheel profile. It can cause various problems during the operation of such a rail vehicle. In addition to the impaired running ability of it, a track is subjected significantly increased additional load, which damages profiles of rails and rail profile. This implies the deteriorated safety of railway operation. Therefore there is necessary such situation investigate and predict in advance. In this work the message, procedure and same results were presented.

Acknowledgements

This work was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 007ŽU-4/2017: Modernization of the Vehicle and engines study programs.

The work was supported by the Slovak Research and Development Agency of the Ministry of Education, science, Research and Sport of the Slovak Republic in Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. VEGA 1/5058/18: Research of the interaction of a braked railway wheelset and track in simulated operational conditions of a vehicle running in a track on the test bench.

References

1. **Bogdevicius, M.; Zygiene, R.** 2017. Dynamic analysis of interaction between vehicle wheel with a metal protuberance and rail, Proceedings of the 17th international conference on mechanics and materials in design M2D2017, Albufeira 17: 1023-1024.
2. **Bogdevicius, M.; Zygiene, R.; Bureika, G.; Dailydka, S.** 2016. An analytical mathematical method for calculation of the dynamic wheel-rail impact force caused, Vehicle System Dynamics 54(5): 689-705.
3. **Brizuela, J.; Fritsch, C.; Ibanez, A.** 2011. Railway wheel-flat detection and measurement by ultrasound, Transportation Research Part C, 19: 978-984.
4. **Chudzikiewicz, A.; Bogacz, R.; Kostrzewski, M.; Konowrocki, R.** 2018. Condition monitoring of railway track systems by using acceleration signals on wheelset axle-boxes, Transport 33(2): 555-566.
5. **Gelumbickas, G.; Vaiciunas, G.** 2011. Analysis of passenger rolling stock faults and its statistics in Lithuania, Transport 26(3): 315-319.
6. **Gerlici, J.; Gorbunov, M.; Kravchenko, K.; Prosvirova, O.; Lack, T.** 2018. Noise and temperature reduction in the contact of tribological elements during braking, MATEC Web of Conferences 157.
7. **Gerlici, J.; Lack, T.; Harusinec, J.** 2014. Realistic simulation of railway operation on the RAILBCOT test stand, Applied Mechanics and Materials 486: 387-395.
8. **Gerlici, J.; Sakhno, V.; Yefymenko, A.; Verbitskii, V.; Kravchenko, A.; Krachenko, O.** 2018. The stability analysis of two-wheeled vehicle model, MATEC Web of Conferences 157.
9. **Grencik, J.; Poprocky, R.; Gallikova, J.; Volna, P.** 2018. Use of risk assessment methods in maintenance for more reliable rolling stock operation, MATEC Web of Conferences, 157.
10. **Harusinec, J.; Suchanek, A.; Loulova, M.; Strazovec, P.** 2018. Design of a device to simulate environmental influences on the course of brake tests, MATEC Web of Conferences 157.
11. **Hauser, V.; Nozhenko, O.; Kravchenko, K.; Loulova, M.; Gerlici, J.; Lack, T.** 2017. Impact of three boxes bogie to tram behaviour when passing curved track, Procedia Engineering 192: 295-300.
12. **Hauser, V.; Nozhenko, O.; Kravchenko, K.; Loulová, M.; Gerlici, J.; Lack.** 2018. Car body and bogie connection modification for track curves passability improvement, MATEC Web of Conferences 157.
13. **Klimenda, F; Soukup, J.** 2017. Modal analysis of thin aluminium plate, Procedia Engineering 177: 11-16.
14. **Kostrzewski, M.; Melnik, R.** 2017. Numerical dynamics study of a rail vehicle with differential gears, Procedia Engineering, 192: 439-444.
15. **Lack, T.; Gerlici, J.** 2014. A modified strip method to speed up the calculation of normal stress between wheel and rail, Applied Mechanics and Materials 486: 359-370.
16. **Lack, T.; Gerlici, J.** 2015. Modified HHT method for vehile vibration analysis in time domain utilisation, Applied Mechanics and Materials 486: 396-405.
17. **Masek, J.; Kendra, M.; Milinkovic, S.; Veskovic, S.; Barta, D.** 2015. Proposal and application of methodology of revitalisation of regional railway track in Slovakia and Serbia. Part 1: Theoretical approach and proposal of methodology for revitalisation of regional railways, Transport Problems: 85-95.
18. **Melnik, R.; Koziak, S.** 2017. Rail vehicle suspension condition monitoring – approach and implementation, Journal of Vibroengineering 19(1): 487-501.
19. **Myamlin, S.; Lingaitis, L. P.; Dailydka, S.; Vaiciunas, G.; Bogdevicius, M.; Bureika, G.** 2015. Determination of the dynamic characteristics of freight wagons with various bogie, Transport 30(1): 88-92.
20. **Pawelczyk, M.; Piotr, L.; Podsiadlo, R.** 2015. Simulation study of the 4-axle wagon damaging impact on the track caused by some deformations of the wheel, Proceedings of 22nd International Conference Current Problems in Rail Vehicles – PRORAIL 2015, Žilina, 22: 115-124.
21. **Saga, M.; Jakubovicova, L.** 2014. Simulation of vertical non-stationary random vibrations considering various speeds, Scientific Journal of Silesian University of Technology – Series Transport 84: 113-118.
22. **Saga, M.; Kopas, P.; Uhricik, M.** 2012. Modeling and experimental analysis of the aluminium alloy fatigue damage in the case of bending – torsion loading, Procedia Engineering 48: 599-606.
23. **Sapieta, M.; Sulka, P.; Svoboda, M.** 2018. Monitoring the fatigue crack on the test specimen during the cycle loading, MATEC Web of Conference 157.
24. **Soukup, J.; Skocilas, J.; Skocilasova, B.** 2017. Assessment of railway wagon suspension characteristics, Mechanical systems and signal processing 89: 67-77.
25. **Soukup, J.; Skocilasova, B.; Skocilas, J.** 2017. Vibration of mechanical system with higher degrees of freedom: solution of the frequency equations, Procedia Engineering 177: 17-24.
26. **Stastniak, P.; Moravcik, M.; Baran, P.; Smetanka, L.** 2017. Computer aided structural analysis of newly developed railway bogie frame, MATEC Web of Conferences 157.
27. **Steenbergen, M.J.M.M.** 2008. Wheel-rail interaction at short-wave irregularities, Delft: Wöhrmann Print Service, Zutphen.
28. **Stopka, O.; Chovancova, M.; Kampf, R.** 2017. Proposal for streamlining the railway infrastructure capacity on the specific track section in the context of establishing an integrated transport system, MATEC Web of Conference, 134.
29. **UIC CODE 518.** 2009. Testing and approval of railway vehicles from the point of view of their dynamic behaviour – Safety – Track fatigue – Running behaviour. September 2009. Paris, France.
30. **Vaiciunas, G.; Lingaitis, L.P.** 2008. Investigating the dynamics of passenger rolling stock deterioration, Transport 23(1): 51-54.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Bicycle as an Element of Shaping the Urban Mobility Policy

M. Dębowska-Mróz[1], E. Ferensztajn-Galardos[2], R. Krajewska[3], A. Rogowski[4]

[1]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: m.mroz@uthrad.pl*
[2]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: e.ferensztajn@uthrad.pl*
[3]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: r.krajewska@uthrad.pl*
[4]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: a.rogowski@uthrad.pl*

Abstract

The implementation of transport needs in cities is an important element in assessing the quality of human life in cities and one of the stages of shaping the policy of mobility in these spaces. Displacements carried out by bicycle are no longer just displacements for tourist and recreational purposes, but are more and more often a way to implement everyday displacements in cities. The development of urban bike systems also affects the increase in the popularity of displacements with this mode of transport in cities. The article presents methods of improving the functioning of cyclists in urban spaces and selected elements of technical and organizational aspects defining a set of basic requirements enabling safe and effective cycling in cities.
KEY WORDS: *urban transport, congestion, city bike, division of transport tasks, mobility policy*

1. Introduction

The bicycle has been used by people for over 200 years. It is considered one of the most perfect devices used for relocations with relatively small terrain and infrastructure requirements, which generates low external costs associated with its operation. For example, field requirements for different forms of displacement in relation to one person in different forms of displacement are [2]:

- pedestrian traffic about 0.75 m^2;
- a tram passenger about 1.5 m^2;
- bus passenger about 2.75 m^2;
- cyclist about 6.8 m^2;
- motorcyclist about 21 m^2;
- car driver about 50 m^2.

The use of a bicycle for everyday displacement is particularly beneficial over short distances. In the European Union, the average distance of most displacements carried out in cities does not exceed several kilometers, and every other trip takes a distance of 5 to 14 km. It is not difficult to notice that if we take into account numerous difficulties resulting from the occurrence of congestion, in many areas of cities a bicycle can be moved faster than by car or public transport. Therefore, it is not surprising that there is a growing interest in this mode of displacement for both people who meet their needs in cities and entities responsible for the functioning of transport systems in these areas, which more and more often indicate the need for proper planning of infrastructure dedicated to cyclists.

2. The Importance of Bicycle Movements in Cities

For years, the bicycle has been seen as one of the ways of displacement that enables everyday needs of people in many European cities, eg in Amsterdam, Copenhagen, every third, and in Delft or Gröningen even every second journey is done with the use of a bicycle. The average share of a bicycle in the total number of trips in the Netherlands is 28%, and in Denmark - 20% [8]. The bike is the main means of getting to work for 11% of Dublin's residents. The share of cycling in the total number of trips exceeds 12% in Berlin, and in Austrian Graz - 14%. Using the bike for everyday displacement is possible even in cities with unfavorable climatic conditions. It is estimated that, for example, bicycle rides represent 25% of all daily trips in the near Arctic Circle of Oulu (Finland).

The share of displacements carried out by bicycle is smaller in Polish cities, it was about 1-2% at the turn of the 20th and 21st century [10]. Currently, interest in using the bike for everyday displacements in Polish cities is increasing. The displacements are carried out as an independent trip or as part of a combined trip with other modes of displacement (means of transport) [9]. For example, the share of the bicycle as a daily mode of displacement was: in Gdansk in 1998 - 1%, in 2009 - 2%, in 2016 6%, in Warsaw in 2015 - 3.8%, and in 2017 - 5.5, in Krakow in 2004 - 1.4%, and in

2016 - 4.6%, in Radom in 2001 - 1.8%, and in 2017 - 6.4%, in Poznan in 2007 - 2.5%, and in 2013 - 4.6%. In addition, the program for a comprehensive approach to the development and functioning of "bicycle communication" adopted in Poznan, in which it was assumed that 10% of all trips will be made by bicycle in 2020 and in 2022 will be 12%.

As part of the project: Integrated planning of sustainable urban transport of the Radom Functional Area, a research team from the Faculty of Transport and Electrical Engineering of UTH in Radom [1], carried out in 2014 surveys on the mobility of Radom residents, including preferences of choosing a means of transport in trips and identification of motivation of displacements (source-destination). The use of a bicycle as a means of transport depending on the age and gender of residents and the motivation of displacements using a bicycle was one of the research elements. The results are shown in Table 1.

Table 1

The average daily number of trips using a bicycle as a means of transport including gender and age groups depending on the motivation (source-target) of displacements

M	Women					Men					Women + Men				
	13-17 lat	18-44 lat	45-59 lat	60+ lat	13+ lat	13-17 lat	18-44 lat	45-59 lat	60+ lat	13+ lat	13-17 lat	18-44 lat	45-59 lat	60+ lat	13+ lat
1-2	0.000	0.010	0.000	0.002	0.005	0.000	0.012	0.011	0.008	0.010	0.000	0.011	0.005	0.004	0.007
1-3	0.016	0.001	0.000	0.000	0.001	0.000	0.003	0.000	0.000	0.001	0.008	0.002	0.000	0.000	0.001
1-4	0.000	0.013	0.003	0.012	0.010	0.000	0.004	0.011	0.015	0.008	0.000	0.009	0.006	0.013	0.009
1-5	0.031	0.008	0.008	0.010	0.010	0.029	0.037	0.011	0.023	0.027	0.030	0.023	0.009	0.015	0.018
1-7	0.000	0.001	0.003	0.000	0.001	0.000	0.001	0.004	0.004	0.002	0.000	0.001	0.003	0.001	0.002
1-8	0.031	0.005	0.005	0.002	0.006	0.014	0.003	0.007	0.000	0.004	0.023	0.004	0.006	0.001	0.005
2-1	0.000	0.010	0.000	0.000	0.004	0.000	0.012	0.011	0.004	0.009	0.000	0.011	0.005	0.001	0.007
2-2	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
2-5	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
3-1	0.016	0.000	0.000	0.000	0.001	0.000	0.003	0.000	0.000	0.001	0.008	0.002	0.000	0.000	0.001
3-2	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
4-1	0.000	0.009	0.003	0.010	0.007	0.000	0.003	0.015	0.023	0.010	0.000	0.006	0.008	0.015	0.009
4-3	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000
4-4	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
4-5	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000
4-8	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
5-1	0.031	0.010	0.010	0.010	0.011	0.029	0.036	0.011	0.015	0.025	0.030	0.023	0.011	0.012	0.018
5-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.001	0.000	0.000	0.000	0.001	0.000
5-5	0.000	0.001	0.000	0.000	0.001	0.000	0.003	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.001
6-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.001	0.000	0.000	0.000	0.001	0.000
7-1	0.000	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.001
7-4	0.000	0.000	0.003	0.000	0.001	0.000	0.000	0.004	0.000	0.001	0.000	0.000	0.003	0.000	0.001
8-1	0.031	0.001	0.003	0.005	0.004	0.014	0.006	0.004	0.000	0.005	0.023	0.004	0.003	0.003	0.004
8-5	0.000	0.001	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.001
A	0.156	0.078	0.038	0.056	0.066	0.086	0.128	0.088	0.099	0.110	0.120	0.104	0.061	0.072	0.086
B	0.031	0.003	0.003	0.000	0.003	0.000	0.006	0.004	0.011	0.006	0.015	0.004	0.003	0.004	0.005
C	756	3192	884	1742	6573	437	5378	1742	1984	9542	1193	8571	2626	3726	16115
D	20.00	3.33	6.67	0.00	4.81	0.00	4.65	4.17	11.54	5.78	12.67	4.16	5.01	6.14	5.39
E	6	16	9	9	20	4	15	10	9	18	6	19	11	13	24
F	6.25	3.66	1.79	2.17	2.94	4.29	5.79	3.69	4.94	5.09	5.22	4.66	2.57	3.25	3.88
G	89.06	67.58	46.55	23.19	52.14	87.14	72.07	53.51	34.98	61.32	88.06	69.68	49.40	27.77	56.17
H	10	60	15	23	108	6	86	24	26	142	16	146	39	49	250

The number of trips made by respondents - 8161.	The share of the trip with the use of a bicycle in total trips - 3.10%.
Estimated average daily number of trips by a resident of Radom - 2,782.	The share of trips combined with the use of a bicycle in total trips - 0.17%.
The estimated daily number of trips of the residents of Radom - 520,200.	The share of bicycle trips in total trips - 2.93%.

M - displacement motivations (source-destination, only trips made by at least one of the groups are indicated): 1 - home: place of residence, 2 - work: place of starting work, 3 - education: schools, universities, place of course, training , 4 - shopping and services: to the kiosk, shop, shopping center, 5 - recreation and entertainment: for sporting purposes, to the cinema, restaurant business matters: all trips made as part of the work, 7 - offices, hospitals, clinics, banks, courts : performed not as part of the job, 8 - other purposes: e.g. - travel for a person, delivery of a person; A - average daily number of trips; B - average daily number of combined trips (bicycle + other means of transport); C - estimated daily number of trips using a bicycle as a means of transport; D - share of combined trips in displacements using a bicycle [%]; E - number of implemented motivations (source-destination); F - the percentage of respondents who made a trip using a bicycle [%]; G - percentage of respondents declaring bicycle use in the season [%]; H - number of trips made by respondents using a bike.

Source: own study based on [1]

Most often, the inhabitants of Radom use bicycles in trips in house-recreation relations (20.9%), recreation-house (20.9%), house-shopping (10.5%) shopping-house (10.5%) and regardless of gender. Only among men, the home-work, home-work relationship outperforms the home-shopping, shopping-home relationship in the "ranking." Differences between age groups are small and result mainly from the specificity of age, for example: young people do not go to work (because they generally do not work), adults over 44 years do not go to school (because they do not usually learn). Among the observations that can be considered unusual is the fact that young people do not use bicycles

to shopping. The low share of combined trips in trips with the use of a bicycle is characteristic (5.39%), of which 43.75% are pedestrian-bicycle trips, 37.5% combined with passenger cars and 18.75% with public transport. The share of combined trips with the use of bicycles accounts for 2.11% of all combined trips - it is therefore nearly one-third less than the trip using a bicycle in the total number of trips. It is also noteworthy that the percentage of people who made a bike trip (3.88%) is higher than the share of bicycle trips in total trips (3.10%). Although the number of trips made by respondents amounted to 8161, the trips made using the bike only 250. Therefore, we should approach with caution the participation of particular source-destination relations, especially in groups in which age and gender were indicated. However, the error in the estimation of the share of trips using the bike in the total number of trips is 0.61 percentage points (with a confidence coefficient of 0.95) and the percentage of people carrying out displacement by bicycle is 0.7 pp.

3. Requirements for the Implementation of Bicycle Movements

Planning of the transport system in cities includes diverse groups of issues that focus mainly on ensuring the implementation of efficient, safe and environmentally friendly displacements taking into account the specific requirements of diverse user groups of these spaces. Persons implementing displacements using a bicycle are the only of such groups. It is worth taking notice of the fact that the role of a bicycle in urban transport can be shaped by the actions of the city authorities and the transport policy they conduct. The cycling development policy should be conceived as an integral element of the entire transport and communication policy. Its implementation must be supported by other areas of the city's activities, such as spatial development, urban development and even social and economic activities. For this reason, some cities approve the technical standards for cycling infrastructure on the basis of a local law act, which is then an act binding on all municipal units (Krakow, 2004, Torun, 2005) [11]. An example of a comprehensive approach to the implementation of transport policy in this respect are: Seville, Paris, Berlin, Helsinki and London, where residents of these cities were encouraged to change from a car to a bicycle through appropriate actions. Appropriate approach to planning infrastructure dedicated to cyclists is largely the reason for the success of such a policy.

Various types of actions and programs aimed at popularizing bicycle movements are implemented in many countries and cities. For example, a national project involving the payment of 25 cents for workers commuting to work by bicycle for each kilometer traveled encourages a change to two wheels in Paris. The campaign "Bike for work, i.e. home, bike, work ... and so on" is being implemented in Krakow for years. The goal of this campaign is to encourage people who travel by car to carry out displacements by bike (own or rental). Entities that want to participate in the project report on behalf of employees the desire to join the project. The increase in the number of people using a bicycle in their daily movements is the result of these activities.

The good practice of creating bicycle infrastructure and organizing bicycle traffic is based on the methodology of the so-called five requirements of the Dutch CROW standardization organization: consistency (100% of sources and destinations covered by the bicycle system), directness (minimizing detours and elongation), convenience (minimizing the delay coefficient, adapting the design speed to the route category and minimizing the gradient gradients and level difference) , safety (reducing the number of collision points with car and pedestrian traffic, unification of speed, elimination of traffic interleaving and ensuring eye contact), attractiveness (the bicycle system should be readable to the user, well-connected to the city's functions, meet users' needs and ensure social security). The five requirements should always be met at the level of: the entire cycling network in a given city space in relation to all types of bicycle communication routes (main, collective and local bicycle routes), individual routes and their sections, specific technical solutions (intersections, crossings, contraflow line, etc.).

The design of bicycle infrastructure carries many benefits to users [4]:

- facilitating traveling without a car;
- improvement of traffic safety;
- shorter travel times in the city center;
- improving the psychophysical condition;
- reduction of travel costs;
- increasing the flexibility of travel.

Benefits for entities responsible for the operation of the transport system in cities [3]:

- changing the division of transport tasks (increasing the share of trips made without cars);
- the possibility of transforming the space of streets and squares;
- reduction of investment and operating costs related to the transport system;
- creating a positive image of the city, open to promoting ecological forms of transport;
- improving public health.

This approach to planned urban spaces also results in benefits for the urban environment [3]:

- improvement of living conditions and the quality of the urban environment (reduction of noise emission and harmful substances released into the air by other means of transport);
- reduction of street congestion by cars (vehicles in motion, as well as space occupied by parked vehicles) with the possibility of using them for socio-cultural purposes;
- strengthening the identification of residents with the city.

Elements of the classic transport infrastructure dedicated to cyclists are: separated bicycle routes outside the

road, small roundabouts with one traffic lane, bicycle locks in the roadway at intersections, cyclists, bicycle stands, lifts, ramps, ramps, bicycle lifts, etc. [6]. In recent years, these elements are additionally supplemented with the so-called elements of invisible bicycle infrastructure: lanes for bicycles in the roadway, lanes enabling “wrong-way-driving”, contraflow lines, zones of Tempo 30 (speed limit up to 30 km/h), intersections equal infrastructure serving cyclists "by the way" - dedicated to cycling and other goals and users: speed bumps - long, plate - raised discs of intersections, traffic islands and reflective pylons, road pillars preventing the entry of undesirable vehicles, barriers.

Activities related to planning the relevant elements of cycling infrastructure should be preceded by the recognition of basic problems accompanying the displacements carried out by cyclists. Such research should include all users who use this space together. To this end, a pilot questionnaire study was carried out in Radom in the spring and autumn of 2016 (on the occasion of collecting data for the diploma thesis by the student P. Petrzak). The research covered a total of 654 people. assessment of the essential elements related to the functioning of the transport system in the aspect of road safety was the goal of these studies. As a result of the analysis, it was found that in the context of cycling displacement the biggest problem perceived by respondents is high traffic volume and aggressive behavior on the part of cyclists (Fig. 1). Modernization of the existing transport infrastructure is also an important task to be implemented in order to ensure the proper functioning of cyclists in cities (Fig. 2). Activities undertaken in this area should cover all possible solutions that in a given traffic and road situation will be best perceived by interested users of these spaces (Fig. 3) [5].

The most important sentences related to the functioning of the cycling system in cities were the separation of space dedicated to pedestrians and cyclists (44%) as well as cyclists and vehicles (39.65%). Not without significance is also the problem resulting from the lack of urban bypasses, which translates into the use of road transport infrastructure by vehicles moving in the transit system in relation to the city. Respondents also well accept changes in the speed reduction on traffic routes, on which cyclists move.

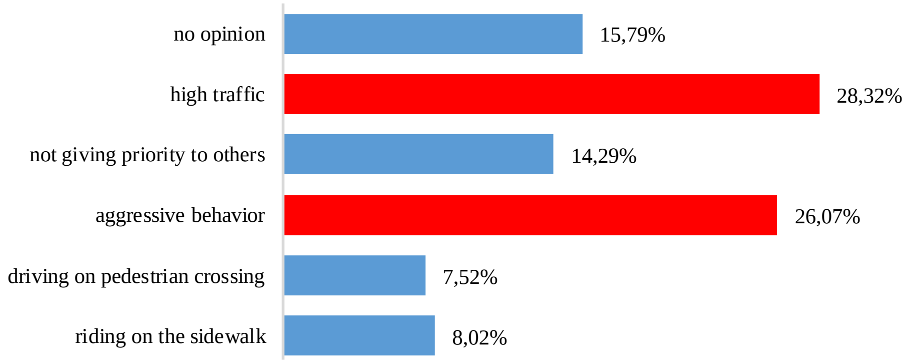


Fig. 1 Basic problems related to functioning in the transport space of Radom in the opinion of respondents

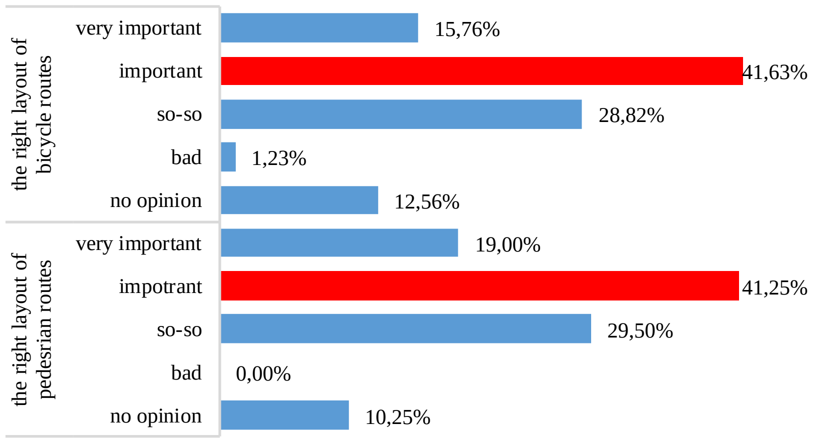


Fig. 2 Meanings of selected elements of transport infrastructure related to displacements carried out on foot and by bicycle

New cycling routes with different parameters are set in Polish cities. Various solutions are implemented to facilitate the displacement by bicycle. Cyclists can use one-way roads (both ways). A separate traffic light for cyclists is an interesting solution. It is allowed to drive on pavements (the maximum permissible speed is then 10 km/h).

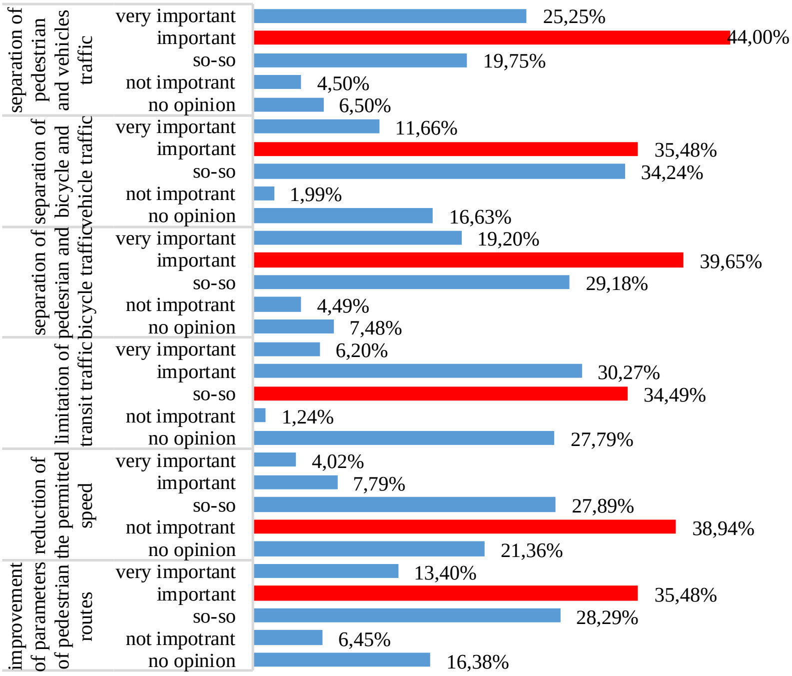


Fig. 3 The scope of required actions to improve the functioning of cyclists

4. City Bike System

The city bike ceases to be the domain of only big cities. The functioning of this system meant that the displacement of bicycles ceased to be perceived as recreational movements. They have become an essential element of the functioning of the transport system in cities that are considered a "variant of the means of urban transport" enabling the implementation of everyday movements of residents and people arriving in cities. Currently, there are over 140 bicycle rental systems in 165 countries around the world [3] (Fig. 4).

Source: [3]

Fig. 4 Location operators of public bike rental system in the world

Diverse public (city) bike systems operate in the largest cities and agglomerations in Poland: Nextbike (27 systems), Bikell (4 systems), Romet Rental Systems (4 systems), Comdrev (1 system), Acro Bike (1 system). The oldest of them is the Wavelo operating in Krakow since 2008 and the largest Veturilo (Nextbike) with 366 stations and almost 5,300 bicycles in Warsaw [7].

The city authorities decide to launch a city bike system for their residents for a number of reasons: increasing the number of everyday bicycle movements, reducing congestion, improving air quality and offering residents alternatives to urban transport in the form of active mobility. In addition, the city bike has two major advantages compared to other transport projects: the implementation costs are relatively low and the duration of the entire project is short. It is possible to plan and implement the system in a really short time, which means that benefits accrued from the system operation can be derived much faster than in the case of other urban transport projects (such as investments in a new tram fleet or the purchase of new buses). In addition, the transport performance of the bicycle is represented by the number of people able to be transported by a given means of transport with a 3.5 m lane in urban conditions within one hour

(persons / h / 3.5 m wide) is one of the highest (car - 2000, bus - 9,000, bicycle - 14,000, pedestrian - 19,000, tram - 22 000) [6]. Low land use and high traffic flow of bicycle transport can be invaluable in ensuring high mobility in urban areas, with particular focus on city centers characterized by dense buildings, permanent space deficits and a very large accumulation of sources and destinations that generate a large number of displacements carried out by various methods.

Over 1 million Poles use the city bike system, and the number of rented bicycles is counted in millions. An important task in the design of public bicycle systems is to consider the appropriate number of stations and their appropriate location taking into account the structure and location of the most important traffic generators taking into account places of residence, work and education. The development of a consistent system of bicycle stations in the city is the goal of this approach. The attractiveness of the public bicycle system may reduce the lack of coherence regarding the location of bicycle stations and the appropriate distances between them. It is worth remembering that the key to the success of public bicycle in the city is cycling infrastructure, the number of stations and their deployment.

The bicycle is an ideal means of transport on the first and last kilometer of movement. We leave the house, take a bike, reach it to the interchange, get for example to the subway, which we go to the center, then we take the bike again and get the destination. This significantly shortens the travel time, partly offloading trams and buses. The price list also influences the popularity of the system. The first twenty minutes are free. In Polish cities in which public bicycle systems operate, 85-90% of travel takes place during these free minutes [12, 13]. This payment system is primarily an incentive for those who are still undecided to use the bike and become convinced of its advantages.

5. Conclusions

It is a serious proposition to plan a coherent transport system in cities, which must take into account the implementation of various transport needs of diverse participants of urban space, including pedestrians and cyclists. It is necessary to take into account the diverse external conditions (e.g. implementation of the sustainable transport development strategy and taking into account the spatial development of the city and transport development) and internal cities (e.g. ensuring good cooperation of urban transport with agglomeration and regional transport, including the existing potential of other transport subsystems operating in the city) when designing such a system.

The shaping of the communication system of residents requires coordination of transport policy with spatial policy in order to reduce transport intensity and ensure proper efficiency of the transport system. The priority of such planning and at the same time meeting the requirements resulting from the strategy of sustainable transport development in the city should be: transforming the city transport network into an efficient and functional element of infrastructure allowing to organize efficient moving of people inside the city in accordance with the expectations of residents and facilitating the movement to external areas. A particularly important task is to solve the problem of satisfying transport needs on short and medium distances, which can be implemented using a bicycle.

References

1. **Ciszewski, T.; Dębowska-Mróz, M.; Ferensztajn-Galardos, E.; Grad, B.; Krajewska, R.; Łukasik, Z.; Rogowski, A.; Wojciechowski, W.** 2014. Analiza przemieszczeń i preferencji komunikacyjnych na obszarze ROF opracowanie zespołu UTH Radom (umowa NR 1/KM4/2014 z dnia 21 maja 2014 r. między SITK Oddział w Krakowie a UTH w Radomiu) w ramach projektu Zintegrowane planowanie transportu zrównoważonego miejskiego Radomskiego Obszaru Funkcjonalnego (umowa MPU-II/3302/4/2014 z dnia 22.04.2014 r. między Miejską Pracownią Urbanistyczną w Radomiu a SITK Oddział w Krakowie), materiał niepublikowany, (in Polish).
2. **Dębowska-Mróz, M.; Lis, P.** 2017. Kształtowanie przestrzeni transportowej dedykowanej pieszym i rowerzystom jako element poprawy mobilności w miastach, Autobusy. Technika, Eksploatacja, Systemy Transportowe 12: 522-527 (in Polish).
3. **Dębowska-Mróz, M.; Lis, P.; Szymanek, A.; Zawisza, T.** 2017. Rower miejski jako element systemu transportowego w miastach, Autobusy. Technika, Eksploatacja, Systemy Transportowe 6: 1173-1182 (in Polish).
4. **Dębowska-Mróz, M.; Rogowski, A.** 2014. Preferencje wyboru środka transportu przez mieszkańców Radomia w świetle badań ankietowych, Logistyka 2/2014: 1292-1303 (in Polish).
5. **Dębowska-Mróz, M.; Rogowski, A.; Szychta, E.** 2014. Ocena infrastruktury rowerowej w Radomiu w świetle badań ankietowych, Logistyka 3/2014: 1284-1291 (in Polish).
6. **Kozłowski, M.** 2014. Analiza możliwości wdrożenia systemu roweru publicznego w Kortowie - Projekt „GREEN UNIVERSITY", Zeszyty Naukowe Instytutu Pojazdów nr 2(98): 127-131 (in Polish).
7. **Nextbike** 2016. Materiał reklamowy, (in Polish).
8. **Shaheen, S.; Guzman, S.; Zhang, H.** 2010. Bikesharing in Europe, the Americas, and Asia: past, present and future, 2010 Transportation Research Board Annual Meeting, March 15.
9. Stowarzyszenie Transportu Publicznego, Biała księga mobilności, www.transport-publiczny.pl/BKM/ BialaKsiegaMobilnosci 2015.pdf.Szczecin, http://bikes-srm.pl/, [online cit.: 2018-04-22], (in Polish).
10. UE 2008, W kierunku nowej mobilności w miastach, Zielona księga UE, Bruksela (in Polish).
11. http://wrower.pl/miasto/rower-miejski-wypozyczalnia-rowerow,2183.html [online cit.: 2018-04-26], (in Polish).
12. http://www.bractworowerowe.ats.pl, [online cit.: 2018-05-22], (in Polish).
13. https://nextbike.pl/news/w-radomiu-wystartowal-pilotazowy-system-rowerow-miejskich, [online cit.: 2018-05-22], (in Polish).

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Possibility of Vibrodiagnostics in Determining Technical Condition of Combat Vehicle Gearbox

C. V. Tran[1], J. Furch[2]

[1]*University of Defence, Kounicova 65, 66210, Brno, Czech Republic. E-mail: caovu.tran@unob.cz*
[2]*University of Defence, Kounicova 65, 66210, Brno, Czech Republic. E-mail: jan.furch@unob.cz*

Abstract

Vibrodiagnostics have been widely used in various industries for a long time. The purpose of this paper is to introduce the possibility of vibrodiagnostics in determining technical condition of gearbox of combat vehicles. Analyzing vibration signals affords a reliable mean to identify specific gearbox faults such as bearing defects, gear tooth damages, and mechanical looseness. In addition, the vibration signals reveal the trendy of mechanical operation in the future that create an advantage in developing a condition - based maintenance. Vibration diagnostics method demonstrates the possibility of determining fault modes, diagnosing technical condition and performing an effective maintenance.
KEY WORDS: *vibrodiagnostics, combat vehicle gearbox, condition indicators, technical condition of gearbox*

1. Introduction

It is the fact that combat vehicle gearbox has to work in overloaded conditions and it is impacted by excited forces; therefore, during the operation, it can witness faults relating to gears, bearing, and shaft. As a result, gearbox is required as an effective maintenance at the precise time. However, in practice, gearbox has been overhauled for many times when no faults have occurred because operating setting time do not meet the condition - based maintenance accurately. If this gearbox still had significant remaining working time, they could be operated for a longer time. The improper maintenance results in the reduction of the reliability of vehicle in operation, catastrophic failures, and high cost of spare parts, etc. Several methods of monitoring and detecting failures of combat vehicle gearbox have been used for such a long period but with limited outcomes. Recently, the vibrodiagnostics have been used in monitoring the technical condition of the gearbox, and the technique uses the vibration signal in order to identify, analyze, detect and diagnose potential failures which cause condition of gearbox as well as improve maintenance approaches. This paper presents the technical condition of military vehicle gearbox, vibrodiagnostics and applications.

2. Gearbox of Combat Vehicle

The combat vehicle has an advantage of mobility especially in heavy terrain, and as a result, high performance and reliable transmissions are the requirement. Transmission system helps to supply torque from the engine to the wheels. Transmission system basically includes clutch, gearbox, drive shaft, universal joints, rear axle, wheel, and tires. The gearbox consists of complex component parts and it has an important role of transmission system. The function of the gearbox is to transmit the torque and rotation from the engine to the driving wheels, in forward and reverse direction, and to provide transmission ratios to adapt speed of engine at the different driving situations. It is the fact that gearbox has to perform with high load and harsh operating condition; therefore, it requires the reliability and durability in operation. There are two mainly types of gearboxes which were used in military vehicle: mechanical gearbox and hydromechanical gearbox.

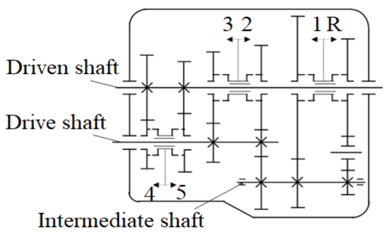
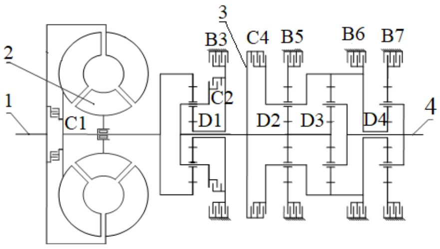


Fig. 1 Schematic dynamic mechanical gearbox Tank T54 [12]

Mechanical gearbox is the simple component that has been widely historically used. The gearbox is combined with all shafts, gearwheels, differential and inner universal forming joints and integral unit. Basically, all forward gears are synchromesh, whereas reverse is couple of sliding gear. The shafts are moved in the gearcase in bearings. The front part of the gearbox assembly consists of a primary drive which is driven by the engine through the clutch and transmitting the engine output to the gearbox itself. The Fig. 1 represents the mechanical gearbox that was equipped with Tank T54 [12]. The mechanical gearbox was simply designed with the purpose of operating and maintaining easily at the low cost. However, this structure has drawbacks; for example, it is incapable to produce various ratios and it can be difficult to

operate for drivers. As a result, this gearbox is equipped with the Light Strike Vehicle (LSV), the first-generation Tank.

Hydromechanical gearbox has a significant potential to increase the drive performance and reduce the consumption of construction machinery. This architecture allows smaller hydraulic components to provide continuously variable transmissions functionality to lager machines in an effective way. The disadvantages of this concept are that they are complex devices, high-cost and requires high-performing workforce. As a result, this type of gearbox is significantly used for the combat vehicle that has high load and extraordinary required mobility such as, Armored Personnel Carrier (APC), All Terrain Vehicle (ATV) and modern tank.



1. Input shaft
2. Hydraulic part (hydraulic transformer torque)
3. Mechanical part (planetary gears)
4. Output shaft

C1, C2, C4: clutches
B3, B5, B6, B7: brakes

Fig. 2 Schematic dynamic planetary gearbox M113 [13]

The Fig. 2 represents the hydromechanical gearbox TX-200 that was equipped with armored personnel carrier M113 [13]. Hydromechanical gearbox includes a hydraulic part and a mechanical part. The former has a hydraulic transformer torque with turbine shaft, pump and turbine wheel, while the latter contains planetary gears system located after the hydraulic transformer. It is also involved with the power and control system that supply the energy path and switch brake and clutch system which result in changing output shaft angular velocity. A turbine shaft of the transmission gear is rigidly attached to the turbine wheel of the hydraulic transformer. Hydraulic transformer is provided with an interlocking friction coupling installed between the pump and turbine wheels. A planetary gear system varies the number of available speed ratios. With three stages and eight selectively operable coupling elements, i.e., four clutches and four brakes, six forward speeds and a reverse speed may be realized. The Table shows the operating couple at the different speeds.

Table

Schematic of operating couple elements of gearbox TX-200 [13]

Speed	**Coupling elements operated**	
	Mechanical	**Hydraulic mechanical**
0		B3
1		B3+B6
2	C1	C2+B6
3		B3+B5
4	C1	C2+B5
5	C1	C4+B3
6	C1	C2+C4
R		B3+B7

In fact, the gearboxes are required with high-performance efficiency, durability and reliability at acceptable levels of noise, vibration and temperature. During the operation, the gearbox occurred failures that affected transmitted ability torque and mobility of vehicle. The majority reasons are that the technical condition of component parts is deteriorated after long-term operation or the insufficient and ineffective maintenance. The gearbox faults are related to gear tooth damages (pitting, wear, plastic flow, breakage), bearing defects (macro pitting, denting, fretting corrosion, scuffing), and mechanical looseness (misalignment, unbalance). Base on the research, the faults of 257 damaged gearboxes were from bearing (occupy 70%), gear (26%) and others (4%) [6].

There are number of methods that were used for monitoring technical conditions of the gearbox. In the monitoring process, the condition of gearbox in relation to physical characteristics is monitored for signs of impending failure. The machines can be monitored that required not only sophisticated instrumentation but also skilled required experts. Condition monitoring provides the link between the recorded data and the health assessment analysis capability. Condition monitoring includes methods such as vibrationdiagnostics, acousticdiagnostics, tribodiagnostics, and thermodiagnostics. Among these methods, vibrationdiagnostics is widely used for a long-term period because of its significant advantages.

3. Possibility of Vibrodiagnostics in Monitoring Condition Combat Vehicle Gearbox

During the operation, the gearbox generates a gear noise and a vibration signal. When a noise or vibration problem arises, it can be correlated with the major failures of gearbox. The study observed and analyzed the vibration signals of gearbox in operation in order to assess the technical condition which is called vibrodiagnostics. Vibration is the motion produced in component parts (gear mesh, bearing, shaft, gearcase) due to the effect of external or in internal forces on the parts. In general, it is possible to consider the vibration part is similar to the spring - mass - damper system. This system involves three fundamental properties: mass (m), stiffness (k) and damping (C) [7]. Vibration analysis is used to determine

the operation and technical condition of machines. A major advantage is that the vibration analysis can identify rising problems before they become more serious and caused unexpected breakdown. Regularly, vibration monitoring can detect the gearbox faults, as an illustration gear damages, bearing defects and mechanical looseness. Analysis vibration signals can be used to identify the health of gearbox and reveal the trendy of maintenance.

In fact, all of the rotated machines, in operation, generate vibrations that are a function of machine dynamics. Measuring the amplitude of vibration at certain frequencies can provide valuable information about the accuracy of shaft alignment and balance, the state of gears or bearings, and the effect on the machine due to resonance from gearcase and other structures. The oscillation can be obtained by the vibration sensors which were classified of measurement parameters, such as: displacement, velocity, acceleration.

To assess the technical condition of gearbox, the condition indicators which are established base on the statistical signal are used. There are three main domains that identified the condition of indicators/parameters of vibration, such as: frequency domain, time domain and combined time - frequency domain. Each parameter refers to the specific characteristics of components. These parameters are formed based on the information contained in the statistical properties of signal.

a) Frequency spectra domain. It is difficult to analyze complex vibration signals in the time domain. As a result, vibration signals are transformed into the frequency domain using Fast Fourier Transform (FFT). The outcome is called a spectrum and it presents the amplitude versus the frequency of the signal components. Analyzing complex vibration signals is a difficult task, because the whole signals is generated by summarizing many vibration sources. Therefore, this method is performed to analyze the specific vibration. Distinctive types of faults are related to the characteristics frequency of these component parts that create vibration. The Fig. 3 shows bearing faults and gear faults in frequency spectra domain.

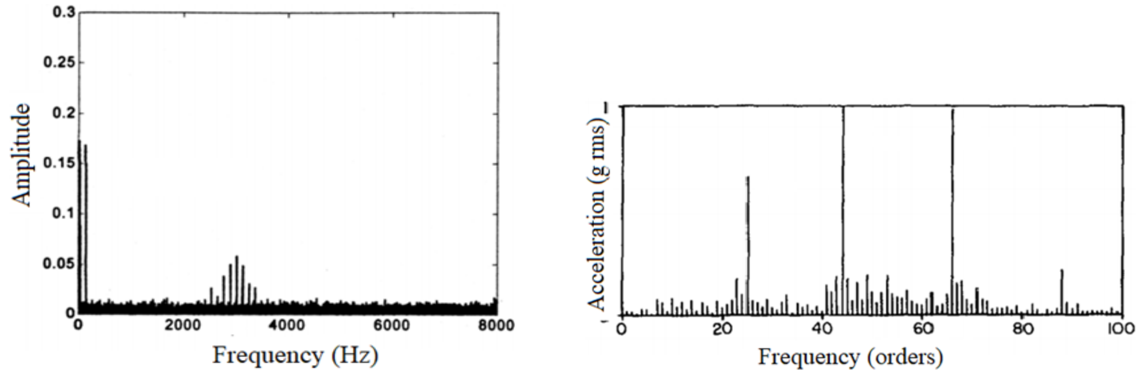


Fig. 3 Spectrum containing typical fault signatures of bearing (left) and gear (right) [2, 3]

It is the fact that, the whole vibration signal which is created by FFT is at the average value, hence the information can be used to determine when at exact point of time, a given transient signal was generated to get lost. Besides, analyzing the spectrum requires the high - skilled expert in order to identify the characteristic of failures. This method cannot be used for quick condition assessment, and as a result, the pre-defined algorithms which are determined the condition monitoring will be required.

b) Time domain analysis. The amplitude, phase, shape and the other information of vibration signal are used as parameters in time domain analysis. This technique is used when the signal is periodic and has no serious interference because a defect may produce periodic impulses over threshold the background. In this case, obviously, the vibration signals can be observed by the waveform. On the other hand, if the signal is not periodic, which often occurs in practice, it is difficult to detect the gearbox faults by only time domain analysis. However, these signals can be used partly of statistical parameters, such as: Root Mean Square (*RMS*), Standard Deviation (*SD*), Crest Factor (*CF*), *Kurtosis*.

Root Mean Square (*RMS*) is used as the most popular indicator that provides an overall view of the vibration signal condition. In mathematical term *RMS* can be expressed as function [9]:

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}}, \qquad (1)$$

here x_i - the signal's amplitude at the *i-th* sample; N - the total number of samples in signal x.

RMS provides information about the energy level of measured signal. It is obvious that, if the fault arises, *RMS* will be higher than its value in the healthy condition. However, *RMS* cannot detect the place where the faults occur. Furthermore, RMS is not sensitive to sudden pulses occurring in short time, for example, the incipient tooth failures [9], but it is more effective if the fault makes a change in overall signal.

Standard Deviation (*SD*) is described as the *RMS* of the deviation of the signal from its mean value. *SD* can be defined as follows [9]:

$$SD = \sqrt{\frac{\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2}{N-1}}\ , \tag{2}$$

here $\bar{x}$ - the mean value of signal *x*.

This parameter can be used to indicate the around fluctuation signal from its mean value [56]. According to the research, the experimental number of spiral bevel gears which were lasted until the tooth is significantly damaged. The SD of instantaneous phase and frequency are demonstrated to be good indicators of pitting; however, it is only clear after the fault occur in the gear [8].

Crest factor (*CF*) is the ratio of the peak value to the RMS of the signal. *CF* can be defined as follows [8]:

$$CF = \frac{max|x|}{RMS}\ , \tag{3}$$

here $max|x|$ - the maximum absolute value present in signal *x*.

In general, peak value is much larger than *RMS* value. Therefore, when peak value changes, result in the *CF* increases and shows the quick overview of impulse occured within waveform. *CF* is applied to monitor the change of the signal pattern due to impulsive vibration sources, resulting from a localized fault such as tooth breakage. *CF* is used to detect the discrete impluse above the background of the signal, which do not occur frequently enough or have extremly short duration to rise significantly the *RMS* value.

Kutorsis is reffered as a non-dimensional quantity which is used to detect the presence of significant peaks in the time domain. It is defined as the fourth normalized moment of the signal [9]. They provide information about the shape of the distribution without the necessity for any information about the signal's probability density function. Moments can be used to indicate the level spread-out of given signal based on the rule that the higher the moment, the more sensitive. That shows the extreme points (tails) in the distribution. *Kurtosis* is defined as [9]:

$$Kurtosis = \frac{N\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2}{\left(\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2\right)^2}\ . \tag{4}$$

*Kurtosi*s is described as a measure of the amplitude distribution peakedness. It is also used as an indicator of major peaks in a set data. When the gear wears and breaks, the vibration levels increase, therefore *kurtosis* show the fault. The disadvantage of *kurtosis* is that when the gear condition deteriorates, more energy is concentrated in the tails of the distribution of the vibration signal that decreases the extent of its peakedness, resulting in falling the *kurtosis* value [5]. Based on the research, *Kurtosis* is used as a reliable measure of a gear crack [2].

c) Time - frequency techniques. Vibration signals that spread in time are called non-stationary signals. The analysis of the vibration signal is concerned with not only what type of fault occurs, but also when it happens. Vibration signal analysis in the frequency domain provide information about the composition of the signal; however, this method will not indicate exactly when the abnormal vibration signals happen. To overcome this problem, a new technique that combined both the time and the frequency domain was developed. Some of the time - frequency techniques are showed:

Short time Fourier transform (*STFT*) is developed from the Fourier Transform techniques to deal with non-stationary data [4]. It is also known as Windowed Fourier Transform. In *STFT*, the signal was divided into shorter parts, after that each part is conducted by FFT. *STFT* is expressed as follows [1]:

$$STFT\left(f,t\right) = \int_{-\infty}^{\infty} x\left(t+\tau\right)w\left(\tau\right)exp\left(-t2\pi f\tau\right)d\tau\ , \tag{5}$$

here *f* - frequency; *t* - time; τ - time delay; $w(\tau)$ - window function; $x(t + \tau)$ - signal to be transformed; $exp(-t\,2\,\pi f\,\tau)$ - Fourier Transform kernel.

The *STFT* can detect an early gear damage [11], and even though the signal is periodic data, where strong harmonic may cover small transient events, the *STFT* can be used to distinguish the characteristics of vibration signal. The limitation of this technique is that the resolution is changed by the window size. The shorter the time window, the better the time domain resolution and the worse the frequency resolution, and vice versa. As a result, the *STFT* is only used in situations where good outcomes are obtained in time or in frequency domain.

Wigner-Ville Distribution (*WVD*) is a bilinear technique that was developed by Wigner and Ville. The WVD is based on the calculation of a correlation of a signal with itself (autocorrelation) to give an energy density. Therefore, WVD is more accurate in time-frequency resolution than *STFT*. WVD is expressed as follows [1]:

$$W\left(f,t\right) = \int_{-\infty}^{\infty} x^*\left(t-\frac{\tau}{2}\right)x\left(t+\frac{\tau}{2}\right)exp\left(-t2\pi f\tau\right)d\tau\ , \tag{6}$$

here $x(t)$ - the analytical form of vibration signal; * - the complex conjugate, f - frequency, t - time, τ - time delay.

The WVD provides the reliable information about the location and the severity of pitting gear. This can detect the gear faults, such as broken tooth, gear crack and localized wear. The advantages of the WVD are that it is optimized in the time and frequency domain and the non-stationary signals show reduced distortion. The disadvantages of the WVD are that it cannot distinguish the local behavior of the data at a given time, and introduces cross-terms when the analyzed signal has many frequency components. Hence, it is difficult to assess quick and reliable the technical condition component.

Wavelet Transformation (*WT*) split the signal into a series functions, namely wavelets located different positions. Local features of a signal can be identified from the scale, which is similar to frequency, and the position in the time axis of the wavelets in which it is decomposed. *WT* is expressed as follows [10]:

$$WT(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi^* \left(\frac{t-b}{a} \right) dt, \tag{7}$$

here a, b - parameters to scale and shift the wavelet, $\psi^*(t)$ - the complex conjugate of wavelet function $\psi(t)$.

4. Conclusions

The paper represents the types of gearbox, such as mechanical gearbox and planetary gearbox that are equipped with combat vehicle. Their hash operation and ineffective maintenance after long-term duration lead to rapidly deteriorating technical condition of component parts related to bearing defects, tooth damages and mechanical looseness. These defects are necessary detected punctually in order to ensure the mobility and readily of combat vehicle in operation.

Vibrodiagnostics uses the vibration signals to identify the health of gearbox. To analysis the signals, the vibration condition indicators that are classified into frequency domain, time domain and time - frequency domain are used effectively. The paper analysis the possibility of these indicators that can used to manifest specific characteristics of gearbox components when the faults occur. However, gearbox is complex machine, therefore, it is necessary that the indicators are combined together to determine accurately technical condition.

Base on the outcomes of measurement vibration, the technical condition is detected and the trendy development of gearbox faults are predicted. As a result, the proper maintenance is selected and the condition - based maintenance is improved.

Acknowledgment

Presented work has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development and Specific Research, Department of Combat and Special Vehicles, University of Defence, Brno.

References

1. **Djurovic, I.; Rubezic**, **V.** 2007. Multiple STFT-based approach for chaos detection in oscillatory circuits, Signal Processing 87(7): 1772-1780.
2. **McFadden, P.D.** 1985. LSow frequency vibration generated by gear tooth impacts, NDT international 18(5): 279-282.
3. **Nikolaou, N.G.; Antoniadis, I.A.** 2002. Rolling element bearing fault diagnosis using wavelet packets, Ndt & E International 35(3): 197-205. **Pryor, A.H.; Mosher, M.; Lewicki, D.G.** 2001. The application of time-frequency methods to HUMS, In annual forum proceedings-American helicopter society 57(2): 1246-1259. American helicopter society, inc.
4. **Samuel, P.D.; Pines, D.J.** 2005. A review of vibration-based techniques for helicopter transmission diagnostics, Journal of sound and vibration 282(1-2): 475-508.
5. **Sheng, S.** 2014. Gearbox typical failure modes, detection, and mitigation methods (Presentation) (No. NREL/PR-5000-60982). National Renewable Energy Laboratory (NREL), Golden, CO..
6. **Smith, J. Derek** 2003. Gear noise and vibration. Marcel Dekker, Inc, 320p.
7. **Smith, S.W.** 1997. The scientist and engineer's guide to digital signal processing.
8. **Vecer, P.; Kreidl, M.; Smid, R.** 2005. Condition indicators for gearbox condition monitoring systems. Acta Polytechnica, 45(6).
9. **Wang, W.J.; McFadden, P.D.** 1996. Application of wavelets to gearbox vibration signals for fault detection, Journal of Sound and Vibration 192(5): 927-939.
10. **Wang, W.J.; McFadden, P.D.** 1993. Early detection of gear failure by vibration analysis i. calculation of the time-frequency distribution, Mechanical Systems and Signal Processing 7(3): 193-203.
11. Tank T-54. Instruction manual for components and operation (in Russian). Ministry of Defense. Moscow
12. Transmission assemblies automatic Allison Division TX 200-2. Department of the Army.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Experimental and Numerical Investigations on Impulse Self-Pierce Riveting of Lightweight Aircraft Aluminium and Mixed Structures

I. Vorobiov[1], N. Nechyporuk[2], K. Maiorova[3]

[1]*National Aerospace University "Kharkiv Aviation Institute", Chkalova 17, 61070, Kharkiv, Ukraine, E-Mail: yuriy.vorobyov@gmail.com*
[2]*National Aerospace University "Kharkiv Aviation Institute", Chkalova 17, 61070, Kharkiv, Ukraine, E-Mail: khai@khai.edu*
[3]*National Aerospace University "Kharkiv Aviation Institute", Chkalova 17, 61070, Kharkiv, Ukraine, E-Mail: astra83@mail.ru*

Abstract

The article provides the analysis of the application scope and installation methods of self-pierce rivets; illustrates the advantages of impulse manual riveting over the impact riveting; lists the specifications of the hand pulse tools engineered in National Aerospace University "KhAI"; provides finite elements method (FEM) modeling results of self-pierce rivets impulse riveting in the aluminum structures and in the mixed ones (aluminum alloys and composites) using Abaqus/CAE software; provides the verification results of the numerical model through matching them with the conducted live experiments results.
KEYWORDS: *self-pierce rivet, finite element model, impulse riveting, hand air-pulse riveting tools*

1. Introduction

Labour intensiveness of assembly processes in aircraft manufacturing exceeds 60% of the total labour intensiveness during the production of modern aircraft, and the production cycle of these works takes up to 70% of the total duration of aircraft production process.

A large share of assembly works is associated with a large number of fixed joints in aircraft structure and works on their sealing.

A large share of labour intensiveness during the rivet installation is connected with hole preparation. The use of self-piercing rivets instead of conventional allows reducing the labour intensiveness of assembly process by reducing the labour intensiveness of the riveted joints implementation by eliminating the need to prepare the holes, as well as their subsequent sealing. Therefore, investigation and development of impulse self-pierce riveting (SPR) technology in aircraft structures is an extremely actual task.

Joining of some aluminium aircraft parts by welding is slightly difficult (only some aluminium alloys have a good weldability), and parts made of composite materials or mixed structures (CM + metal) is not impossible at all. Riveted joints don't have these disadvantages.

General classification of the riveting technological process and the place of impulse riveting that we propose are performed on the Fig. 1. As you can see we propose single impact direct riveting using hand-held pneumatic impulse hammers.

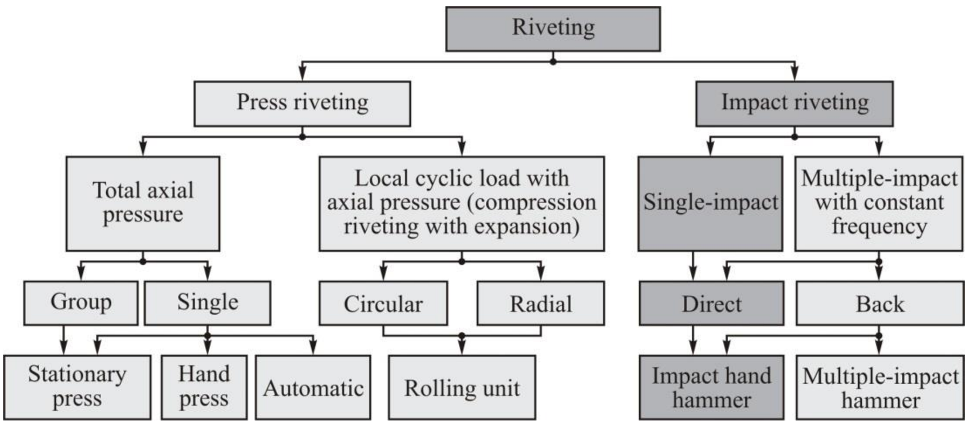


Fig. 1 Classification of the riveting technological process

The main advantages of impulse riveting, in general, are as follows:

- high stability of joint parameters;
- radial interference can be controlled along thickness by forming speed and conditions;

- increased static and fatigue strength, joint tightness;
- no delamination;
- joint quality non-dependent on worker's skills;
- less noise and vibration;
- appropriate hand tool can be created.

A special place among the modern types of riveted joints takes SPR.

SPR is a cold joining process used to fasten two or more sheets of material by driving a rivet through the top sheet(s) and upsetting the rivet, under the influence of a die, into the lower sheet without piercing it. The principal scheme of the process is shown in Fig. 2 [1].

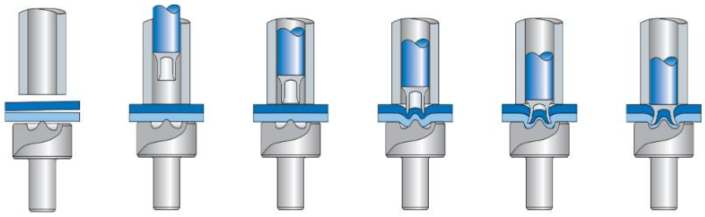


Fig. 2 Principal scheme of the joint formation using a self-piercing rivet

Benefits of using SPR technology [2]:

- joins a range of dissimilar materials such as steel, aluminium, plastics, composite materials;
- can fasten stacks of 2 or more layers; current applications include up to 12 mm total thickness in aluminium and 6mm in steel;
- will not damage coated or painted surfaces;
- provides repeatable joint strength;
- eliminates hole preparation;
- can replace expensive, multi-piece fasteners;
- Provides superior static and dynamic load-carrying capabilities.
- Because the bottom layer is not pierced, an SPR joint can prevent the ingress of liquids or gases through the fastened joint.

Benefits of SPR in comparison to welding [2]:

- SPR can join dissimilar materials.
- SPR installation equipment is operator- and environment-friendly:
  - no cooling water or fume extraction is required;
  - no waste products are generated – noise levels are low, typically < 80dBa.
- Riveted joints can be checked visually for proper fastening.
- SPR is compatible with adhesives and sealants, including layered sheets.
- SPR can be used on coated and painted surfaces and will create better joints even on steel with thicker coatings of zinc.
- Because SPR is a cold form process, distortion due to heat-affected zones is eliminated.

At present, the setting of self-piercing rivets is implemented mainly by manual riveting (using hand-held C-frame riveting devices) and automatic press riveting with a shaped die. Thus there is the need to ensure the alignment of the "riveting set – rivet – bucking tool". Because support has a well-matched profiled surface any deviation from the coaxiality will change the pattern of deformation and lead to rejecting.

Application of impulse setting method of considered rivets allows to eliminate the need in a profiled die due to changes in the metal behaviour under high-speed deformation, and therefore eliminate the need to ensure accurate positioning of the riveting set, rivet and bucking tool relative to each other.

Fig. 3 ThyssenKrupp Technologies tool for impulse installation of self-piercing rivets

1.1. Existing Impulse Equipment for SPR

Recently, the industry uses a tool for impulse installation of self-piercing rivets of ThyssenKrupp Technologies Company (Fig. 3) [3]. However, this tool is quite bulky (weight over 50 kg) and can be used either stationary or in combination with robotic equipment.

1.2. Analysis of the Latest Research and Publications

Due to the fact that the concerned issue is developing and entirely new, there is some limited information available.

In addition to studies presented in this article, similar studies have been carried out by Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz and Laboratory of Materials and Joining Technologies, LWF, University of Paderborn, Germany [4]. Experiments were carried out on aluminium samples for two values of riveting set speed: 10 m/s using air cylinders and 100 m/s using explosives. Riveting performed without C-frames and using a flat bucking tool.

2. Problem Statement

The aim of the study is to identify the possibility of self-piercing steel rivets installation by pneumatic impulse hand-held riveting hammer in the aircraft constructions made of aluminum alloy as well as mixed structures; creation of valid FE model which allow determining the necessary energy parameters of the impulse self-pierce riveting process for different geometry of the riveted joint.

To achieve this goal the following tasks have been formulated and solved:

1. An exploratory experiment is conducted.
2. Energy parameters of the process (initial deformation rate and impact energy) were determined experimentally.
3. FE model developed and confirmed by natural experiment results.
4. The necessity of polyurethane clamp usage is stated in those cases when the top sheet is relatively thin.

3. Experimental and Numerical Procedure Description

3.1. Experimental Investigations Description

Self-piercing rivets with countersunk head with a diameter of 3.5 mm were used for riveting. Manufacturer of rivets is Henrob Corporation (Germany). The stack of parts to be joined consisted of 3 sheets AA5052 with a total thickness of 2.4 mm.

We proposed a technology of self-piercing rivets installation using hand-held pneumatic impulse riveting hammers (Table 1), which is highly mobile and can be used in places with limited access [5, 6]. Riveting was performed using flat bucking tool.

Table 1

KhAI Pneumatic Impulse Riveting Hammers

Parameters	Riveting Hammer types	
	HPI-90M (МПИ-90М)	HPI-4 (МПО-4)
		
Impact energy (at 0.5±0.1 MPa), J	90	70
Rivet diameter, mm: - B65 alloy - BT16 alloy or 12X18H9T steel	 6 4-5	 5 3
Cycles, impact per min	60	50
Gun handle force, N	0…5	0…5
Trigger force, N	1.5…2.0	1.5…2.0
Dimensions, mm	420×90×200	350×70×190
Weight, kg	3.5	1.8
Air consumption per cycle, $m^3 \times 10^3$	from 0.4 to 0.5	from 0.3 to 0.4

Pneumoimpulse riveting hammers developed at National Aerospace University “KhAI” have the following advantages [7-9]:

- High stability of the impact energy.
- Possibility of slide control of the impact energy so the influence of the staff skills on riveted joints quality is eliminated.
- Better conditions of work.
- Design simplicity.
- High rate of cycling.
- High-efficiency factor.
- Using of low-cost, easy to use, available and traditional at plants source of energy (air compressed up to 0.5±0.1 MPa).

Experiment was conducted in accordance with scheme presented in Fig. 4.

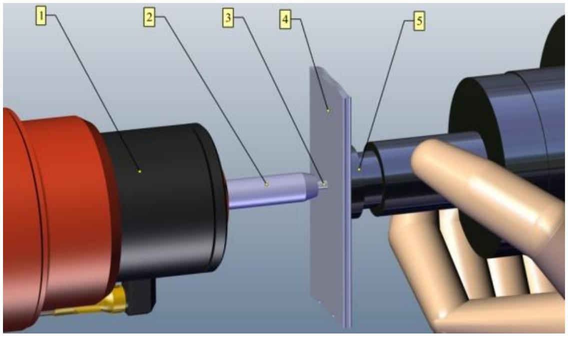


Fig. 4 Principal riveting scheme accepted for the experiment: *1* – pneumatic impulse riveting hammer, *2* – riveting set, *3* – self-piercing rivet, *4* – stack, *5* – bucking tool

Process energy parameters were chosen according to [7]. In accordance with this work the approximating dependence to determine initial riveting set velocity and impact energy depending on supply line air pressure for pneumatic impulse riveting hammer mod. HPI-90M with titanium striker and titanium riveting set at mass 0.14 kg are as follows:

$$\left.\begin{aligned} \bar{\vartheta}_{riv.set} &= 64.1 \cdot P_z^2 - 18.4 \cdot P_z + 22.2; \\ \bar{E}_{riv.set} &= 334.8 \cdot P_z^2 - 151.6 \cdot P_z + 51.1, \end{aligned}\right\} \qquad (1)$$

here $\bar{\vartheta}_{riv.set}$ – initial riveting set velocity; $\bar{E}_{riv.set}$ – impact energy; P_z – air pressure of supply line.

Considering the fact that the alloy AA5052 has a relatively low yield strength and tensile strength it was decided to perform riveting with the air pressure of supply line P_z = 0.3 MPa.

Based on the above empirical relations the initial velocity and impact energy of riveting set will be $\bar{\vartheta}_{riv.set} = 22.4$ m/s and $\bar{E}_{riv.set} = 35.8$ J.

Dependence diagrams of initial velocity and impact energy of riveting set are presented in Fig. 5.

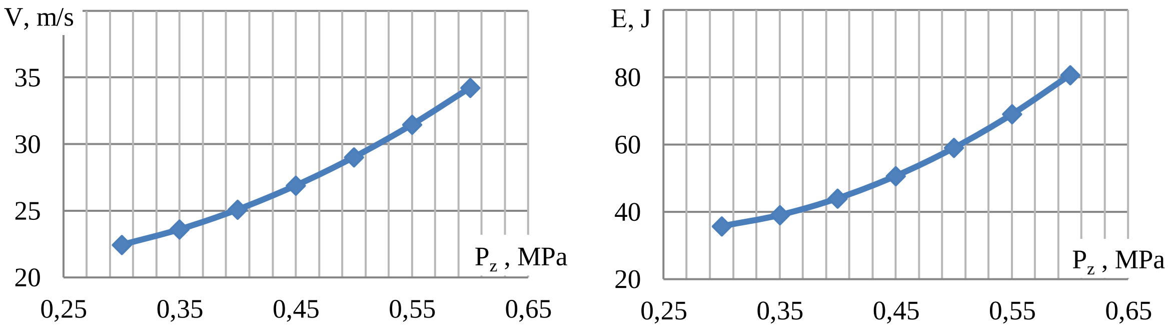


Fig. 5 Riveting set velocity and impact energy depending on supply line air pressure for pneumatic impulse riveting hammer mod. HPI-90M

Recommended bucking tool weight for pulse riveting is $m_{buck.tool} = d_{riv}$ [7], here d_{riv} – rivet diameter, mm. So bucking tool weight is $m_{buck.tool} = 3.3$ kg.

3.2. Numerical Investigations Description

Modelling of self-pierce impulse riveting technological process was performed using software package Simulia/Abaqus.

Explicit method of differential equations integration was used during the simulation, as it is suitable for fast dynamic processes, such as impact, impulse loading, and crash simulation.

Two schemes were considered for simulation:

1. Design scheme without clamp (Fig. 6) used for modeling of thick (stiff) stacks riveting.
2. Design scheme with polyurethane clamp (Fig. 7), which is adopted in the case when the top sheet is relatively thin, to avoid swelling of the top sheet. Proposed polyurethane clamp is installed directly on riveting set.

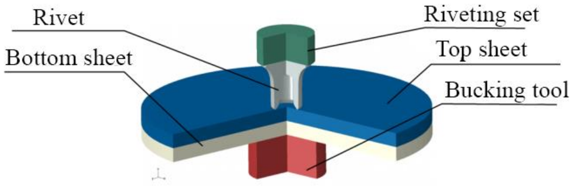


Fig. 6 Design scheme without clamp

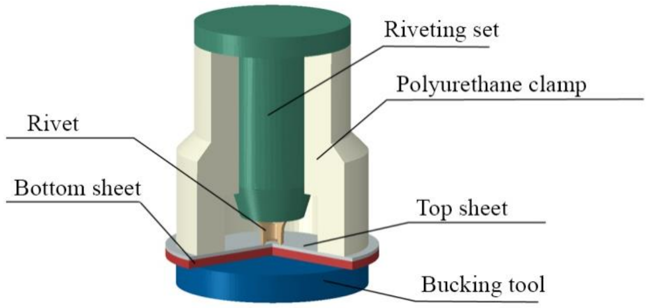


Fig. 7 Design scheme with polyurethane clamp

Geometric parameters of self-piercing rivet are taken from macrosection photographs performed on a scanning electron microscope with a low vacuum chamber and energy dispersive microanalysis system SEM-106. According to information received from rivet macrosection photos, a solid model has created in the system Catia and subsequently imported into Abaqus/CAE to create FEM.

Stack consisted of three sheets AA5052 with a total thickness of 2.4 mm. Rivet material is boron vanadium steel SAE 10B35. The material of polyurethane clamp is СКУ-7Л. Metal material properties are given in accordance with hardening diagrams, and for polyurethane – in accordance with uniaxial stress/strain test data.

To simplify finite element model it was decided to conduct calculations for the sector of 10° value. This procedure allows to decrease the number of finite elements and as the result to reduce calculation time.

Under large deformations, elements can degenerate. Therefore to avoid this we used ALE Adaptive Mesh.

The most appropriate finite element type for the considered problem is a solid element C3D8R – eight-node brick element with reduced integration. Default values of hourglass control were used.

General contact was used to determine interactions between model parts. General contact applies interactions to all external surfaces including rigid bodies.

Accepted friction coefficient is $\mu = 0.2$ [10].

During the simulation the following assumptions are accepted:

1. Riveting set and bucking tool are Rigid bodies.
2. Mass of riveting set and bucking tool is placed in the centers of gravity.
3. Speed effects for material AA5052 considered by using dynamic coefficient for aluminum alloys $K_d = 1.3$.
4. The problem is solved for the sector of 10˚.
5. Friction on the contact surfaces is described by Amontons-Coulomb Law.
6. Thermal effects caused by plastic deformation are not considered.

4. Results

4.1. Experimental Results

After conduction of riveting experiments obtained joints were cut and polished to perform a qualitative assessment.

Fig. 8 shows the results of impulse self-pierce riveting ($\bar{\vartheta}_{riv.set} = 23.6$ m/s and $\bar{E}_{riv.set} = 39.0$ J) of a stack consisting of 3 sheets AA5052 with a total thickness of 2.4 mm. As you can see we have got tight join, the rivet is upset completely without piercing lower sheet. Static and fatigue strength of this joint should be further tested experimentally. This result indicates relatively optimal energy parameters of the joint formation.

Fig. 8 Result of self-piercing rivet installation in stack consisting of 3 sheets AA5052

The results of impulse self-pierce riveting ($\bar{\vartheta}_{riv.set} = 22.4$ m/s and $\bar{E}_{riv.set} = 35.8$ J) of the mixed stack that consists of 1.5 mm carbon fibre and 0.8 mm AA5052 (Fig. 9).

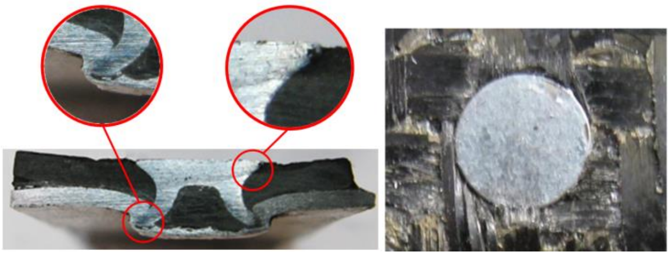


Fig. 9 Result of self-piercing rivet installation in mixed stack

As you can see rivet is upset completely without piercing lower sheet, but there is a delamination of the upper surface of the top sheet, which is probably connected with excessive deformation energy, as well as non-optimized geometry of the rivet head.

4.2. Numerical Results

Numerical modelling of self-piercing rivet installation with the press, which was performed by other authors, is presented in articles [10-12]. As the result of modelling, we have got patterns of stress, velocity, and displacement distribution. Fig. 10 shows the stress distribution in accordance with Mises criteria in different time periods.

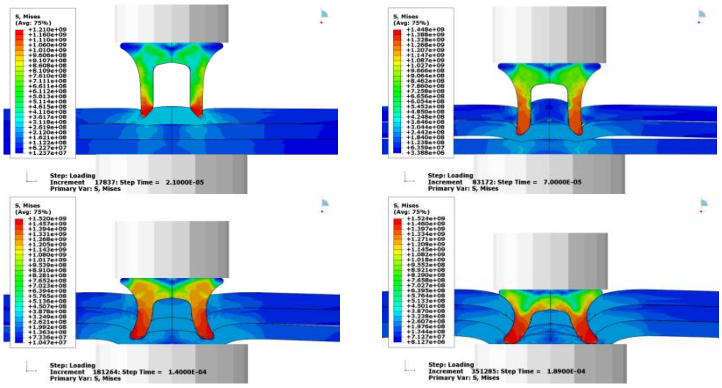


Fig. 10 Stress distribution in accordance with Mises criteria in different time periods

To assess the adequacy of the developed FE model comparison with experimental data is performed. Comparison is conducted according to the deformed stack and rivet contours that are obtained during the simulation and the experiment. Results of the comparison are presented in Fig. 11.

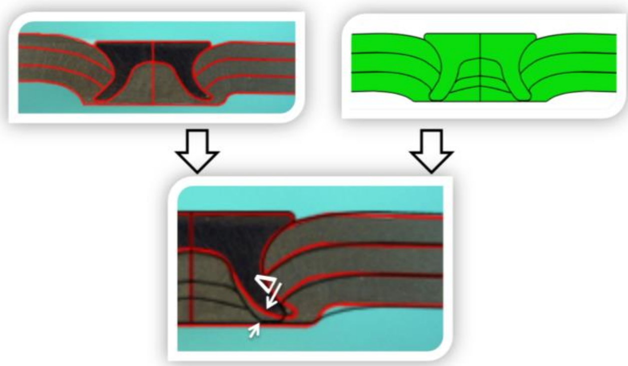


Fig. 11 Comparison of the simulation results and experimental data

As it can be seen from the figure above simulation results converge quite accurately with the experimental data. This fact indicates the adequacy of the developed FE model. The maximum deviation Δ between contours is 0.21 mm.

To prove the effectiveness of polyurethane clamp usage the simulation of impulse self-pierce riveting was conducted without clamp (Fig. 12) and using it (Fig. 13). The simulation was carried out according to a previously developed finite element model, the adequacy of which has been proven.

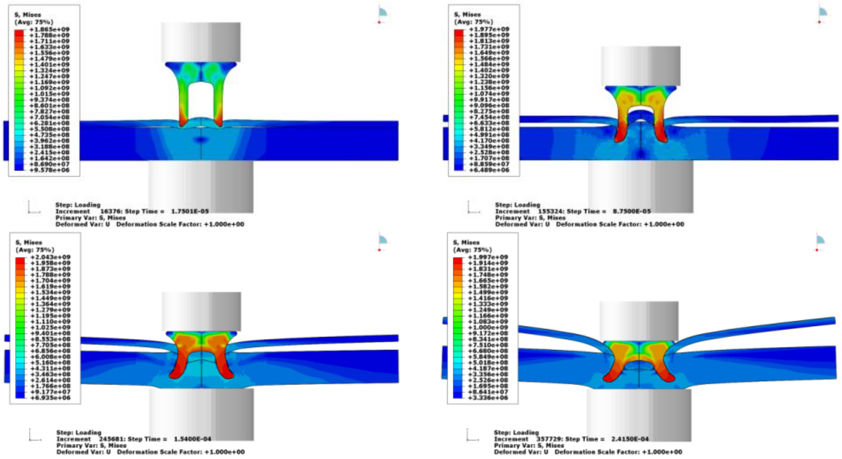


Fig. 12 Simulation of the impulse self-pierce riveting process without clamp

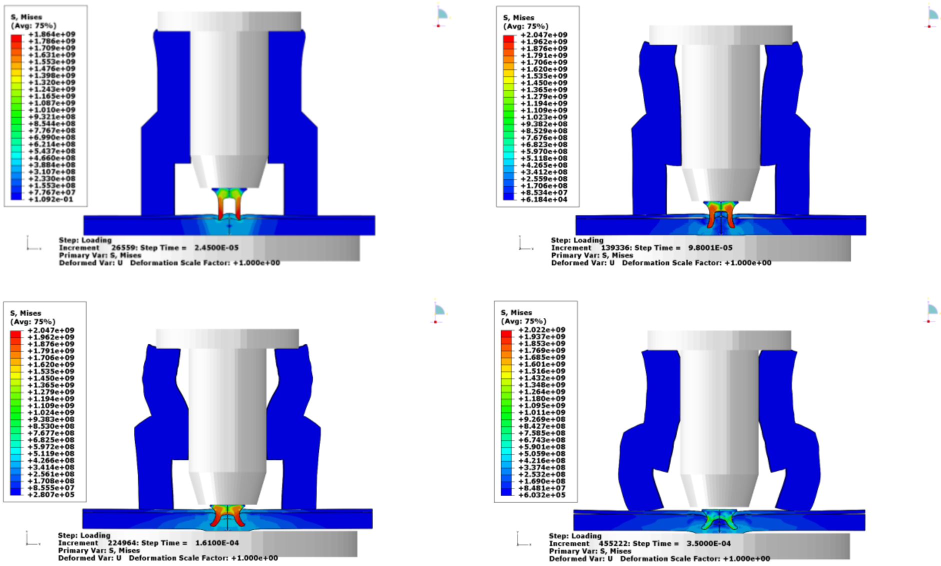


Fig. 13 Simulation of the impulse self-pierce riveting process using polyurethane clamp

5. Conclusions

Experiments have been conducted on impulse riveting by hand-held pneumatic impulse riveting hammer using steel self-piercing rivets of stacks consisting of aluminum alloy AA5052 with a total thickness of 2.4 mm, as well as mixed stacks consisting of carbon fiber and aluminum alloy mentioned above with total thickness of 2.3 mm. Results of experimental studies have proved the possibility of joints formation using proposed impulse method. Initial energy parameters of the process are obtained. Additional experimental and numerical studies are needed to find the rational riveting process parameters.

Finite element model of impulse self-pierce riveting technological process also developed in frames of the study. The model verification is conducted by comparison of the simulation results with the experimental data. It was found that the developed FE model provides quite good convergence with the experimental data. The maximum deviation between the deformed contours was 0.21 mm.

The necessity of polyurethane clamp usage is proven for stacks with a relatively thick top sheet. The clamp usage eliminates swelling of the top sheet during riveting.

References

1. Extremely strong joints in one step [online cit.: 2018-05-17]. Available from: http://www.boellhoff.de/de/de/verbindungselemente/spezial-verbindungselemente/niettechnik/stanzniete-rivset.php
2. Henrob Self-Pierce Riveting Technology (HSPR) [online cit.: 2018-05-17]. Available from: http://www.crawford-products.com/media/Henrob_Crawford.pdf
3. **Neugebauer, R.** 2009. Joining by forming. Fraunhofer IWU, 2 s.
4. **Hahn, O.; Neugebauer, R.; Leuschen G.; Kraus, C.; Mauermann, R.** 2008. Research in Impulse Joining of Self Pierce Riveting, 3rd International Conference on High Speed Forming: 173-180.
5. **Kudrja, V.; Babuschkin, A.; Knigin, V.; Lepetjucha, V.** 1983. Hygienic aspects of the pulse riveting hammers

application, Aircraft Industry 6: 83-85.

6. **Tshistjak, V.** 1986. Research of the process, development and introduction of the technology of pneumatic impulse riveting of aircraft structures by high-resource rivets, Doctor’s degree in specialty 05.07.04 – aircraft manufacturing. Kharkiv Aviation Institute, Kharkiv, 163 s. (in Russian).
7. **Vorobiov, I.** 2004. Development of technological process and tool for pulse riveting of aircraft structures from carbon plastic. Doctor’s degree in specialty 05.07.04 – aircraft manufacturing. National Aerospace University “Kharkiv Aviation Institute”, Kharkiv, 166 s. (in Russian).
8. **Vorobiov, I.** 2003. Determining the cost-effectiveness of introducing pulsed riveting technology, Aerospace technic and technology 1(36): 76-81.
9. **Vorobiov, I.; Kuschnarenko, S.; Stepanenko, V.** 2004. Choice of rational parameters of pulse riveting technological process and instrument of aviation structures from carbon plastic, Open Information and Computer Integrated Technologies 24: 131-135.
10. **Porcaro, R.; Langseth, M.; Weyer, S.; Hooputra, H.** 2008. An experimental and numerical investigation on self-piercing riveting, International Journal of Material Forming 1(1): 1307-1310.
11. **Krishnappa, U.S.** 2008. Numerical investigation of self-piercing riveted dual layer joint, Master of Science Thesis, Wichita State University, Kansas, United States: 88 s.
12. **Porcaro, R.; Hanssen, A.; Langseth, M.; Aalberg, A.** 2004. Through process modelling of self-piercing riveting, Metal Forming: 8th International LS-Dyna Users Conference 13: 7-16.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Cargo Securing and its Economic Consequences

M. Vlkovský[1], P. Veselík[2], D. Grzesica[3]

[1]*University of Defence, Kounicova 65, 662 10, Brno, Czech Republic, E-mail:* martin.vlkovsky@unob.cz
[2]*University of Defence, Kounicova 65, 662 10, Brno, Czech Republic, E-mail:* petr.veselik@unob.cz
[3]*University of Technology, Warszawska 24, 31-155 Kraków, Poland, E-mail:* dgrzesica@pk.edu.pl

Abstract

The paper deals with the economic aspects of cargo securing in relation to higher transport safety. Cargo securing is currently considered a solved area, although standards regulating this issue contain data (acceleration coefficients) that were measured in the late 1980s. Differences in transport systems across the EU compared to the past (in 80´s) are obvious. Preliminary analysis indicates that current conditions in the transport market may not correspond with input data for fastening cargo. Statistical analysis of the measured data values of the acceleration coefficients have been done in this article. Data are graphically visualised and evaluated by proper statistical applications. Based on the results, recommendations for effective securing of cargo, including economic evaluations of the researched problem, are mentioned.
KEY WORDS: *cargo securing, transport system, transport market, acceleration coefficients, descriptive statistics, exploratory data analysis, normality tests*

1. Introduction

The growing demand for transport cargo in the Czech Republic (CR) recognizes growth in road transport. The Czech Republic represents a transit state for Europe and the cargo transport situation is different compared with that of the transport market in the European Union (EU) as a whole (EU-28).

In 2016, a total of 431,889,000 tons of cargo was transported within the Czech Republic, which is more than 21% higher than in 2010 [1]. During the same period (2010-2016), the situation in the EU-28 was dissimilar, because it showed a decrease from 15,045,637,000 tons of transported cargo on the road to 14,645,052,000 tons, a decrease of almost 2.7% [2]. Nevertheless, the situation in some states is analogous to that of the Czech Republic where there has been a larger or smaller increase in the volume of cargo transported on the road. These states are, include the neighboring countries of Germany, Poland, Austria and Slovakia.

Interestingly, the situation during the last two years for which data are available (2015 and 2016) while there was a slight decrease in freight transport in the Czech Republic (by less than 1.6%) in the EU-28, that decrease measured more than 2.4% [1, 2].

Over 76% of all cargo is transported across Europe by road [3], which is why so many roads are overloaded. According to data from the Road Transport Services Center, which was established by the Ministry of Transport of the Czech Republic (MD CR), there are over 2,000 weight inspections per year, where nearly half the vehicles are overloaded [4]. The stated amount of transported cargo (transport performance) makes a high claim on road infrastructure that is more quickly damaged. Annual maintenance is not always able to provide the required quality of road infrastructure. The good example may be the main road ("artery") of the Czech Republic, represented by the D1 motorway.

Road quality (among other things) directly affects values of inertia forces affecting the cargo during transport. Generally, on a damaged road, which is characterized by a large number of unevennesses (holes, bumps, etc.), it is assumed that higher values of the acceleration coefficients exist, whose magnitude directly affects the magnitude of the inertia forces. On the basis of these assumed values of inertia forces during particular transport, appropriate methods of securing the cargo and the lashing capacity of the respective fastening means must be chosen.

According to estimates by the European Commission Transport Department, up to 25% of truck accidents are due to incorrect or insufficient cargo fastening [5]. An important aspect is the fact that the cargo or fastening can be damaged without a traffic accident. The economic impacts can be much greater than those directly resulting from traffic accidents.

The official statistics of the Czech Statistical Office (CSO) and The Ministry of Transport of the Czech Republic do not mention the number of road traffic accidents, so the Police of the Czech Republic were used, listing 11,117 traffic accidents caused by truck drivers in 2016 in the Czech Republic [6]. The total number of traffic accidents in the Czech Republic, which in total is up to 21,386 [1] in 2016, account for more than 52% of traffic accidents caused by truck drivers. The number of traffic accidents caused by truck drivers increased by less than 5% compared with 2015 [6].

Assuming that a quarter of all truck accidents, more than 13% of the total number of traffic accidents were caused by incorrect or insufficient cargo securing, it is a more important factor than the percentage of alcohol-related traffic accidents. In 2016 there were 1,802 alcohol-related traffic accidents, which represent just over 8% of the total

number of traffic accidents [1].

From the economic point of view of the transport market, it can be said that the aforementioned problems are associated with potentially large losses, whether in the form of human lives, damage to health or property damage. Furthermore, overloaded cargo transport is accompanied by significant negative externalities, which are reflected in significantly higher maintenance and repair costs for road transport infrastructure.

The aforementioned estimate by the European Commission The Department of Transport mainly includes two major areas:

a) negligent infringements of regulations where many transport and forwarding companies do not fasten cargo for road transport at all or choose a fastening system that is the quickest (simplest) or requires a minimum of fastening means; the reason is usually the acceleration of loading operations (loading and unloading) or ignorance of the particular fastening method (e.g. non-standard handling units); such a method of fastening does not normally correspond to the effect of the assumed values of the inertia forces on the cargo;

b) cargo securing with respect to all known principles and regulations, which may not apply to all transport conditions (e.g. transport on damaged roads, vehicle in very poor technical condition or to a driver whose driving style is too aggressive) and may not correspond to the actual values of the inertia forces affecting the cargo during transport.

This article will also focus on the secondary category of causes of traffic accidents which are due to incorrect or insufficient fastening of the cargo (e.g. due to inadequate values of acceleration coefficients). For this purpose, the transport experiment was accomplished and the resulting data analysed by appropriate statistical methods.

2. Literature Review

Cargo securing issues are subject to a large number of standards, publications and manuals. Standards primarily address general principles and requirements in the field of cargo securing. Publications in journals and conference proceedings mainly discuss specific issues and models. Guides and guidelines are generally created by interested organizations, or transnational companies in a particular market segment (for a specific group of commodities) for each mode of transport.

The basic source of principles and calculations for Cargo Securing is the ČSN EN 12195-1:2011 standard, which contains empirically determined acceleration coefficients and formulas for the calculation of various fastening methods using fastening straps [7]. Other sources of information used in the EU are usually based upon this standard.

There are plenty of instructions, manuals and codes in the EU that are created by the European Commission, or more precisely by the Directorate-General for Energy and Transport, or one of the internationally recognized organizations such as the International Maritime Organization or International Labor Organization. In crucial EU documents we find examples of EU best practices prepared by the European Commission's Directorate-General for Energy and Transport 2014 „European Best Practice Guidelines on Cargo Securing for Road Transport“, which mainly elaborates the standard ČSN EN 12195-1:2011 in specification of selected terms and areas and in terms of practical principles of cargo fastening [5].

An interesting source of information also includes national approaches. Germany is a leader in Europe in the field of principle and adaption issues of cargo securing, while transporting the largest volume of cargo in Europe every year. While the EU-28 average was over 523,000,000 tons in 2016, in Germany 3,111,858,000 tons of cargo were transported in that year, representing over 21% [2].

The problem of cargo securing on the road is very well dealt with in the instructions of the Association of German Engineers "VDI 2700 Securing of Loads on Road Vehicles". The instruction mainly discusses two basic methods of cargo securing – blockage and friction bonding, including their use in combination [8]. The practice Code of the UK Derartment of Transportation from 2002 also has an analogous focus „Safery Loads on Vehicles“ which, apart from methods of fastening, also solves the technical means used for these purposes [9].

In scientific monographs, references to cargo securing in relation to the values of shocks (acceleration coefficients) during transport usually are part of more general topics from logistics and transport and there are no studies that discuss aspects of data sources and methodology of the standard ČSN EN 12195-1:2011. Other monographs focus on specific problems of cargo securing during the transport of abnormal or dangerous cargos.

A monograph that does deal with cargo securing with the use of (among others) fastening straps, is the book „Cargo Securing in Road Transport Using Restraining Method with Top-Over Lashing” by Tone Lerher [10]. The author deals with both general rules of cargo securing on road and the fastening of cargo using fastening straps, namely Top-Over Lashing.

Equally important is the case study that is part of the monograph, where an analysis of fastening cargo efficiency is performed with respect to the key parameters of the calculation, such as the dynamic coefficient of friction or the angle that the strap forms to the plane of the load compartment [10]. Another monograph is from 2007, the Grossmann and Kassmann book "Safe Packaging and Load Securing in Transport”. They also present in their book, in addition to packing functions, methods of fastening cargo, including strapping cargo models using fastening straps [11].

Articles in journals are sporadically focused on discussing transport parameters and, in rare cases, directly by normative requirements, but they are usually only partial applications (models).

Verification of the selected calculations in EN 12195-1:2011 deals with an article [12] where the author also discusses determination of the required number of fastening means using the input data and the formulas of the standard. Verification of the strength of the fastening straps using the EN 12195-2:2003 methodology, inter alia with regard to

their damage, is discussed in the article [13].

A number of publications discuss the issue of cargo securing and road safety in a selected regions (country, Europe) based on international or European legislation, such as [14] or [15]. The broadest group of publications are articles in journals and conference proceedings focused on the vehicle (with cargo), its technical parameters and its speed, using a simulation software (e.g. MSC.ADAMS) for making models and simulations, [16] or [17].

3. Research Approach and Methods

The aim of this paper – case study is to illustrate a model using data from the accomplished transport experiment that, despite compliance with all the known principles of cargo securing, the lashing of the cargo may not be sufficient and there is a risk of traffic accidents, loss of lives, injuries, as well as damage to cargo or any other technical devices such as trucks or infrastructure.

Among the main aspects that affect the value of inertial forces affecting the cargo during a transport are included:

a) roadways;
b) vehicles (with/without cargo);
c) driving styles (especially speed).

Apart from the technical parameters and the technical condition of the vehicle, it is important whether it is or it is not loaded and more specifically, the weight of the load. The speed of the vehicle is decisive for the driving style of the driver. This paper also focuses on the first aspect, that is the quality of the roadway, which directly affects cargo lashing requirements.

Data of transportation with the Fiat Ducato vehicle with a cargo of 800 kg (8 pallet units) was measured for this purpose. The vehicle was in a good technical condition with less than 70,000 kilometers. The transportation route was mostly on the highway (D1, D8, A17 and A4) from Popůvky (near Brno, Czech Republic) to Ottendorf-Okrilla (near Dresden, Germany). Short sections of the lower-class road and driving breaks were removed to maintain the homogeneity of the dataset. The total route was 366 km and the vehicle was driven less than 280 minutes (4:39:59). The average vehicle speed was approximately 78.4 $km \cdot h^{-1}$.

Shocks (acceleration coefficients) were recorded by the OM-CP-ULTRASHOCK 5-CERT accelerometer with datalogger and the appropriate calibration certificate. The measurements were taken for each axis (X, Y and Z) and recorded every second of the transport [18]. The axes are signed in standard way, as:

- X axis is longitudinal to the vehicle movement;
- Y axis is transverse to the vehicle movement;
- Z axis is vertical to the vehicle movement.

Acceleration coefficients for each axis (c_x, c_y and c_z) are dimensionless and indicate shocks as a multiple of a gravity acceleration, which determines the resulting acceleration (a). For the model presented, the (absolute) value of the individual acceleration coefficients is decisive, not their direction, which expresses by mark. E.g. a negative value of c_x means a shock – acceleration in the opposite direction to the direction of the vehicle movement.

The basic factor affecting the cargo, vehicle or crew is the inertia forces that affect them during the particular transport. Using the weight of the cargo and the second Newton's law of motion:

$$F = m \cdot a, \tag{1}$$

where m denotes mass and a is acceleration.

It is easy to calculate the inertia force in the individual axes (F_x, F_y a F_z). Measuring range of the accelerometer is ±5g except the Z axis, for which the coordinate axis is moved from 0 to 1, which corresponds with the effect of the gravity acceleration of 1g [19]. The measuring range for the Z axis is bottom bounded by the coordinate axis, value 1. Using the accelerometer were obtained 16,805 values of the acceleration coefficients for each of the three axes (designation N) during the transportation, a total of 50,415 values. The values were then compared with the normative values of the acceleration coefficients, which are the following for each axis:

- c_x = 0.8/0.5 (forward/backward movement);
- c_y = 0.5/0.6 (shifting/tilting);
- c_z = 1.0 (vertically downwards) [7].

For further analysis, a vector – normatively determined basal variant is used, which considers the displacement of the coordinate axis:

$$c = (0.8; 0.6; 2.0). \tag{2}$$

We can consider basal variant – vector as the worst possible according the normatively set values on [7]. Measured data were ordered by their value, and then the basic descriptive characteristics were calculated. In the following phase the histograms and Q-Q plots were drawn for all the axes [20] and normality tests were performed. Since the measured data cannot be considered as a sample from the normal distribution in all axes, further analysis were carried out assuming alternative distribution. Point and interval estimates of the alternative distribution were calculated to determine the probability of exceeding the normatively determined values of the acceleration coefficients.

Let $x_1, x_2, \ldots, x_n$ be a random selection of the range n from the alternative distribution $A(\pi)$ [22]. It is basically a vector consisting of zeros and ones, depending on whether the specific element has the desired property or not (0 – not exceeded norm, 1 – exceeded norm). If we add the number of obtained zeros and ones, we get the total number of exceeded normalized values. The sample mean then indicates the number of exceedance of the norm in the entire dataset. The search for the estimate $\hat{\pi}$, is basically an estimation of the parts of elements which have the desired property.

The 100(1 – α)% confidence interval of parameter π, $\alpha \varepsilon (0,1)$, is given by [22]:

$$\left(p - u_{1-\frac{\alpha}{2}} \sqrt{\frac{p(1-p)}{n}}; p + u_{1-\frac{\alpha}{2}} \sqrt{\frac{p(1-p)}{n}} \right), \tag{3}$$

where p denotes the point estimate of the proportion of number of ones and total number of measurements ($p = \hat{\pi}$), $u_{1-\alpha/2}$ is 100(1-α/2)% quantile of normal distribution N(0,1).

Lastly, by use of a simple economic analysis we provided an estimate of losses associated with incorrect or inadequate fastening of cargo to the vehicle.

4. Discussion and Results

4.1. Statistical Analysis of Measured Data

After a graphic representation of the average values of the acceleration coefficients in all three axes (Fig. 1) it was found that the systematically highest values are measured in the Z axis. This is confirmed by the results of the basic descriptive characteristics listed in Table.

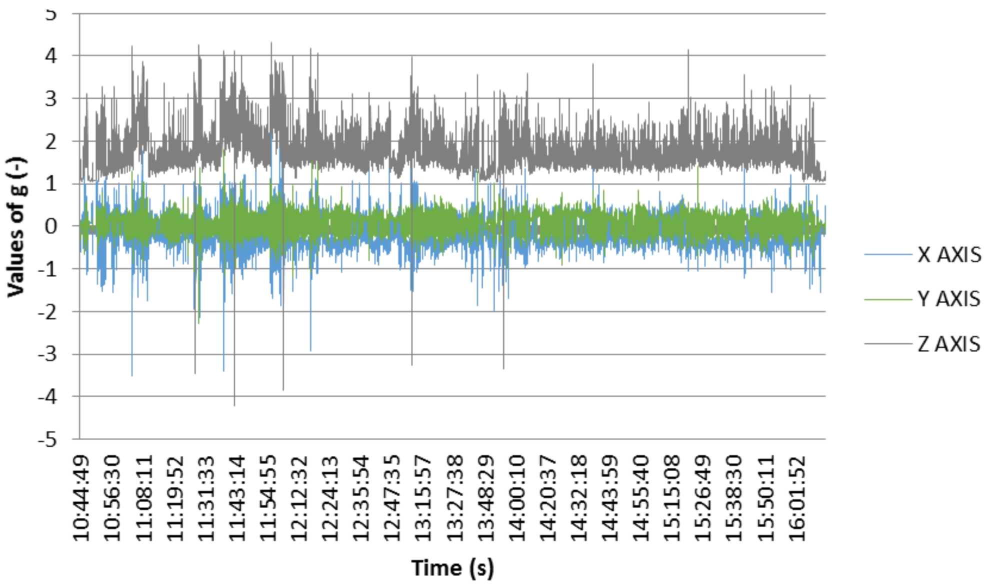


Fig. 1 Measured values of acceleration coefficients in the individual axes

From the Table it is obvious, that the highest value in the positive direction for the measurement day (4.310) was measured in the Z axis and the lowest value in the negative direction (–3.510) was in the X axis. These extremes are important from a cargo securing point of view, because they represent a strong fluctuation that can cause damage or release of the cargo resulting in a traffic accident.

Table

Descriptive characteristics of average values of acceleration coefficients for all axes

Day of measurement	**2017-07-18**		
Axis	X	Y	Z
N	16,805	16,805	16,800*
Mean	**–0.253**	0.103	**1.738**
Mode	–0.330	0.250	1.480
Max	2.710	2.790	**4.310**
Min	**–3.510**	–2.290	–**
Variance	0.116	0.062	**0.185**

**5 removed values from the dataset were measurement errors*

***missing value caused by measuring range of the accelerometer*

The highest amount of these fluctuations above normatively set values was measured in the Z axis, a total of 3,323. The average value of the acceleration coefficients was lowest in the X axis (–0.253), vice versa the highest was in the Z axis (1.738) – see Table. From the variance values in the individual axes, the greatest variability of the measurement is evident in the Z axis.

Before statistical analysis, tests of normality were performed, normality was verified using Q-Q plots, histograms and χ^2 goodness-of-fit tests. The Q-Q plots were drawn for each individual axis of the acceleration coefficients. If points in the Q-Q plot lie approximately on a line, we can assume that those data come from normal distribution [21]. In Fig. 2, Q-Q plots of X and Y axis are shown.

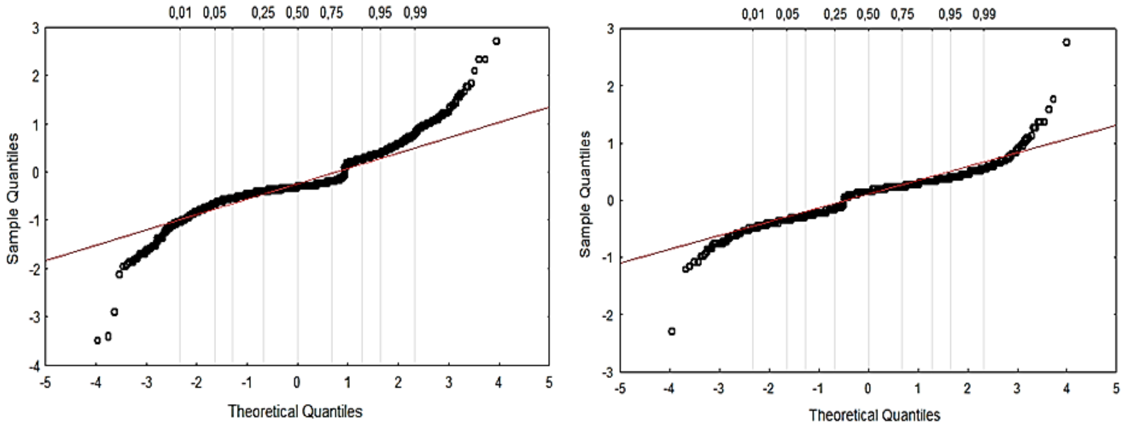


Fig. 2 Q-Q plots for measured acceleration coefficients values in X axis (left) and Y axis (right)

Data in the left and right column are not normally distributed (p-value of the χ^2 goodness-of-fit test is $< 1\times10^{-6}$). Goodness-of-fit tests were carried out on the significance level of 5%. Because the distribution of measured data was asymmetrical (verified by Q-Q plots and Pearson's χ^2 test), the reason data cannot be considered a sample from normal distribution.

The proportion of time on the given section, in which the norm was exceeded, is 3.59% in the X axis, 1.05% in the Y axis and 19.78% in the Z axis. The 95% confidence intervals are then for the X axis (3.3%, 3.9%), for the Y axis (0.9%, 1.2%) and for the Z axis (19.2%, 20.4%).

From the above it is clear that the norm is most often exceeded in the Z axis. Thus the probability of the norm exceeding in all axes is 0.78% and the 95% confidence interval for a total exceeding of the all normatively stated values of the acceleration coefficients is (0.6%; 0.9%). The probability of their double exceeding is 0.22% in the X axis, 0.05% in the Y axis and 0.05% in the Z axis. The probability that, on a given section in a randomly chosen moment, the norm will be double exceeded, is the highest in the X axis.

4.2. Economic Analysis of the Examined Problem

Traffic accidents, which generate damage to health and property, are substantial primarily from the economic point of view. A certain shortcoming is the absence of all statistics on car accidents. These are, in particular, those who have not suffered from injuries or significant damage to property and the police were not called for these car accidents.

According to the traffic police, the estimated material damage during traffic accidents was 5.804 billion CZK in the Czech Republic during 2016, which compares to 2015 as approximately 7% increase [6]. Thus, the average damage for car accidents is 271,392 CZK. If 52% of those traffic accidents are caused by truck drivers, trucks are responsible for material damage in a total amount of 3.018 billion CZK.

If the 25% of them are caused by insufficient cargo securing, then this cause amounts to a potential material damage of 754.5 mil. CZK. Again, it can be assumed that real material losses are even higher and not all truck accidents are included in the statistics. The specificity of trucks compared with passenger cars is also part of the loading procedure, where in the event of incorrect loading procedures and subsequent fastening of the load, accidents may also occur. Such accidents, which occurred prior to the beginning of their own transport are either not recorded at all or only by the company or contractor.

If we presume that at least half of the material damage falls to the examined area (see significant area b) above), the above mentioned problem incurs potential material damage of **377.3 mil. CZK**.

Including damage to the health of people expressed in money, the resulting number would be significantly higher. For this purpose, the model of the Transport research center can be used, which made estimates of the economic loss from traffic accidents relating to killed and injured persons in 2015 [23].

Analogically, the model financial losses could be quantified in 2016 for each area the following way:

- 12.703 billion CZK for 611 persons killed (up to 30 days after the traffic accident[1]) in all traffic accidents in the Czech Republic in 2016 [1, 6, 23], of which 318 fatalities are accounted for trucks, ie. 6.611 billion CZK;
- 12.654 billion CZK for 2,514 severely injured [6, 23], of which 1,307 severely injured accounted for trucks, ie. 6.579 billion CZK;
- 15.921 billion CZK for 24,501 slightly injured [6, 23], of which 12,741 slightly injured accounted for trucks, ie. 8.279 billion CZK.

The presented model is based on insurance company data and includes insurance event data in connection with car accidents. Although the price of life is often criticized from an ethical point of view, the model only discusses actual social losses as a result of slight or severe personal injury, respectively their deaths as a result of a car accident. From this point of view, this is not an ethical, but an economic problem and the price of life, respectively its loss can be understood only as a social loss expressed in monetary units.

With use of methodology of the Transport research center makes the model (long-term) economic impact from the fatalities, severely and slightly wounded during traffic accidents of trucks to a total of 21.469 billion CZK in 2016. And analogically, if we assume, that 25% of the traffic accidents of the trucks are caused by the monitored causes and at least half of them are caused unintentionally, the total financial loss is **2.684 billion CZK**.

5. Conclusion

From the conducted case study, it becomes obvious that cargo securing, considering different acceleration coefficients, can be significant problem that has its own economic consequences. By a statistical evaluation of the experimentally obtained data, we found that the standard is most often exceeded in the Z axis with a probability of 19.78%. The 95% confidence interval for this axis is then (19.2%; 20.4%). Exceeding the normatively set values of the acceleration coefficients in the Z axis happens in almost one fifth of the transportation time. Note also the probability of double exceeding the normatively set values that are not high (0.22% for the X axis, 0.05% for the Y axis and 0.05% for the Z axis), but present a high risk of loosening the cargo and even potentially the cause of a traffic accident.

The results of simple economic analysis show that by considering all losses – ie. material damage and model financial losses attached to traffic deaths, including severely and slightly injured people, the total financial losses are 3.061 billion CZK. This number is valid as an estimate for trucks and selected causes, ie. incorrect or insufficient cargo fastening that are not caused by negligence, but ignorance of the correct values of acceleration coefficients.

Part of the economic analysis might even include other aspects such as environmental damage, psychological damage of traffic accident victims, or other impacts that show themselves over a longer time horizon.

Acknowledgements

The paper was written with the support of the project of long-term strategy of organization development: ROZVOLOG: Development of Capabilities and Sustainability of Logistics Support (DZRO ROZVOLOG 2016–2020) funded by the Ministry of Defence of the Czech Republic.

References

1. Ročenka dopravy 2016 [online cit.: 2018-05-22]. Available from: http://www.sydos.cz/cs/rocenka-2016/rocenka/htm_cz/index.html
2. Goods transpot by road [online cit.: 2018-05-15]. Available from: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=ttr00005&plugin=1
3. **Fenollar-Solvay, A. et al.** 2016. New Intermodal Loading Units in the European Transport Market. Proceedings of Automation, Communication and Cybernetics in Science and Engineering Conference, Cham 687–697.
4. Mobilní expertní jednotky [online cit.: 2018-05-05]. Available from: http://www.cspsd.cz/mobilni-expertni-jednotky
5. Road Safety: Best practice guidelines on cargo securing and abnormal transport. [online cit.: 2018-06-01]. Available from: https://ec.europa.eu/transport/road_safety/topics/vehicles/cargo_securing_loads_en
6. Statistiky nehodovosti 2015 a 2016 [online cit.: 2018-05-06]. Available from: http://www.policie.cz/clanek/ statistika-nehodovosti-900835.aspx?q=Y2hudW09Mw%3d%3d
7. ČSN EN 12195-1. Zajišťování břemen na silničních vozidlech – Bezpečnost – Část 1: Výpočet zajišťovacích sil. Praha: Úřad pro technickou normalizaci, metrologii a státní zkušebnictví, 2011. 48 s.
8. VDI 2700. Securing of loads on road vehicles – Securing of skips on skip loader vehicles and their trailers. Berlin: Verlag, 2009, 34 p.
9. Code of practice – Safety of loads on vehicles [online cit.: 2018-05-15]. Available from: https://assets.publishing.

[1] The number of killed persons varies according to the data of the Czech Statistical Office and the Police of the Czech Republic (Transport Police). The Czech Statistical Office in the Transport Years Report mentions traffic deaths within 30 days after a traffic accident, whereas the Police of the Czech Republic records traffic deaths during traffic accidents. For the purposes of the model, the number of deaths of the Czech Statistical Office is taken, and the difference is deducted from the data of severely injured from the statistics of the Czech Police.

service.gov.uk/government/uploads/system/uploads/attachment_data/file/411093/safetyloadsonvehicles.pdf
10. **Lerher, T.** 2015. Cargo securing in road transport using restraining method with top-over lashing. New York: Nova, 76 p.
11. **Grossmann, G.; Kassman, M.** 2018. Transportsichere Verpackung und Ladungssicherung. 3rd ed. Renningen: Expert Verlag, 152 s.
12. **Jagelčák, J.** 2007. Equation of the standard EN 12195-1 stipulates unreasonable demands for cargo securing, Communications 4(9): 30-33.
13. **Zamecnik, J. et al.** 2017. Influence of a lashing strap winding in tensioning ratchet on the results of the strength tests and cyclic loading tests according to the standard EN 12195-2, Communications 2(19): 10-17.
14. **Banner, S.** 2005. Restraining order, Commercial Motor 5133(201): 54-59.
15. **Cieśla, M.; Hat-Garncarz, G.** 2013. The problem of proper cargo securing in road transport-Case study, Transport Problems 4(8): 27-33.
16. **Zong, Ch.** 2014. The difference and validation of cargo securing rules for road transport in major countries. Proceedings of the 14th COTA International Conference of Transportation Professionals, Changsha: 853-863.
17. **Linins, A.; Berjoza, D.** 2010. Experimental investigation in acceleration of vehicle. Proceedings of International Scientific Conference on Engineering for Rural Development Location. Jelgava: 149-153.
18. **Vlkovský, M. et al.** 2016. The Cargo Securing Based on European Standards and its Applicability in Off-road Transport Conditions. Proceedings of the International conference on Traffic and Transport Engineering, Belgrade: 603-607.
19. **Vlkovský, M.; Šmerek, M.; Michálek, J.** 2017. Cargo Securing during Transport depending on the Type of Road. World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium – Procedia Engineering, Prague: 245: 1-9.
20. **Johnson, R.A.; Wichern, D.W.** 2002. Applied multivariate statistical analysis. 6th ed. New Jersey: Prentice Hall, 773 p.
21. **Veselík, P.; Dvorská, A.; Michálek, J.** 2017. Half a year of co-located gaseous elemental mercury measurements: investigation of temporal changes in measurement differences, Fresenius Environmental Bulletin 26(5): 3128-3137.
22. **Neubauer, J.; Selačík, M.; Kříž, O.** 2016. Základy statistiky: Aplikace v technických a ekonomických oborech. Praha: Grada, 278 s.
23. Dopravní nehody nás v roce 2015 stály 68 miliard, zemřelo 737 osob [online cit.: 2018-05-01]. Available from: https://www.cdv.cz/tisk/dopravni-nehody-nas-v-roce-2015-staly-68-miliard-zemrelo-737-osob

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Operation of a LPG Vapor Phase Fuel System Under the Conditions of Non-Standardized Driving

D. Szpica

Bialystok University of Technology, Faculty of Mechanical Engineering, 45C Wiejska Str., 15-351 Bialystok, Poland, E-mail: d.szpica@pb.edu.pl

Abstract

The paper presents the results of research performed on a vapor phase LPG powered vehicle. The operating parameters were recorded using a dedicated device reading signals from the LPG system. The investigations were carried out under actual traffic conditions during non-standardized driving. The values of individual control and adaptation parameters were evaluated. The results may be helpful not only to validate the correctness of the engine adaptation to alternative fueling but also as reference parameters in the investigations related to the subassemblies of LPG systems or mathematical modeling.
KEY WORDS: *combustion engines, fuel supply, testing, passenger car*

1. Introduction

Out of many alternative fuel systems applicable in transport, the most widespread in Europe are LPG ones [1]. The LPG conversion in vehicles consists in fitting of a separate fuel system that adapts its operation by utilizing the signals from the sensors and actuators. Modern systems are most commonly the vapor LPG multipoint injection ones using pulse injectors. These systems are universal, adaptable to individual engine types and models using manufacturer software [2]. There are very few cases of adaptation-related issues [3]. In terms of functionality, LPG systems are consequently modernized and adapted to the new potential of gasoline fueled engines (for example OBD). External parameters of LPG fueled engines differ, on average, by 10% depending on the type of system [4] burning the majority of fuel in the liquid state. Comparative research is conducted mainly under the conditions of standardized driving cycles [5]. Therefore, it is justified to perform trials under the conditions of regular driving, outside of laboratory (non-standardized driving). In this way, data can be obtained that could be used not only for functional analysis but also for calculations or simulations.

2. Object of the Research

The research object was a 2004 BMW X3 E83 of the mileage of 110 000 km. The originally fitted fuel system of this engine (M50B25) was a multipoint indirect fuel injection. The basic technical specifications have been shown in Table 1.

Table 1

Basic technical data of the BMW X3 E83 (2004)

Engine:	R6, 24V, gasoline
- engine displacement	2498 cm^3
- max. power at engine speed	141 kW / 6000 min^{-1}
- max. torque at engine speed	245 Nm / 3500 min^{-1}
- injection system	multipoint
- compression ratio	11.0 : 1
- fuel-air mixture composition regulation	wideband lambda probe
Transmission:	GM, automatic

The vehicle was converted to an alternative LPG fueling system (in Poland referred to as the IV generation LPG). This is a system that, in the final stage of operation, utilizes vapor phase LPG pulse injectors. The individual components of this system have been presented in Fig. 1.

The LPG system was mainly built from the AC S.A. components (Table 2).

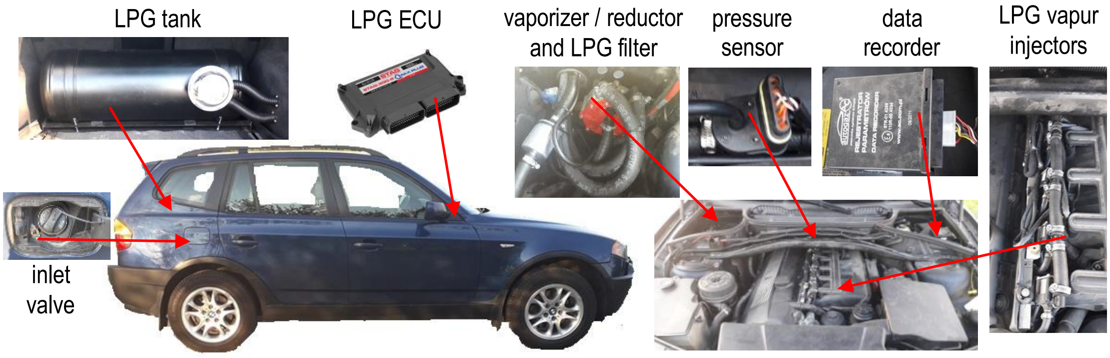


Fig. 1 Location of the LPG system components in the BMW X3 E83 research object

Table 2

The basic elements of the LPG system

LPG ECU	STAG AC QMAX -6 PLUS
vaporizer / reductor	STAG AC R01 250HP
LPG vapour injector	STAG AC W03
pressure sensor	STAG AC PS04
data recorder	AC

It was calibrated statically and dynamically using the AC STAG software. During the calibration, the injection times when fueled with gasoline and LPG were compared (Fig. 2). On this basis, the coefficient was determined that confirmed the correctness of adaptation of the universal LPG systems to a given vehicle model. A significant spread of the points around the trend line was visible (Fig. 2) for the injection times greater than 8 ms for LPG fueling.

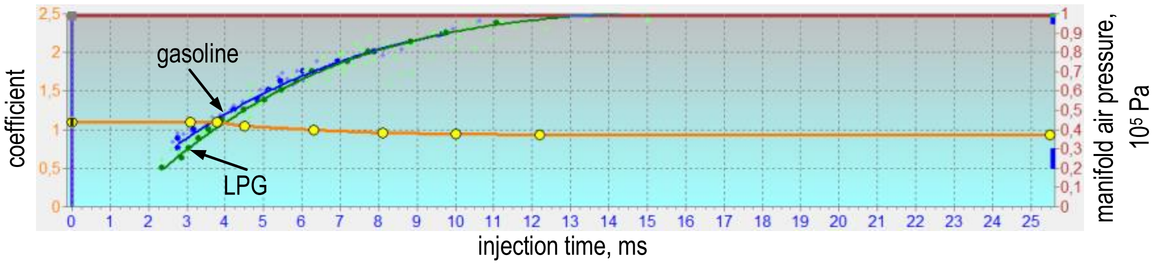


Fig. 2 Comparison of the gasoline and LPG (AC STAG) injection times

3. Research Methodology

For the recording of the signals pulled from the LPG ECU, a data recorder (AC S.A.) was used. This is a 'black box' type device that, upon establishing connection with the controller, cyclically pulls the engine related data. Additionally, there exists a possibility of recording of a specified event by pressing a button fitted in the driver's cockpit. The values are recorded on a memory card as the .osc file, which enbales later retrieval in the AC STAG software (Fig. 3).

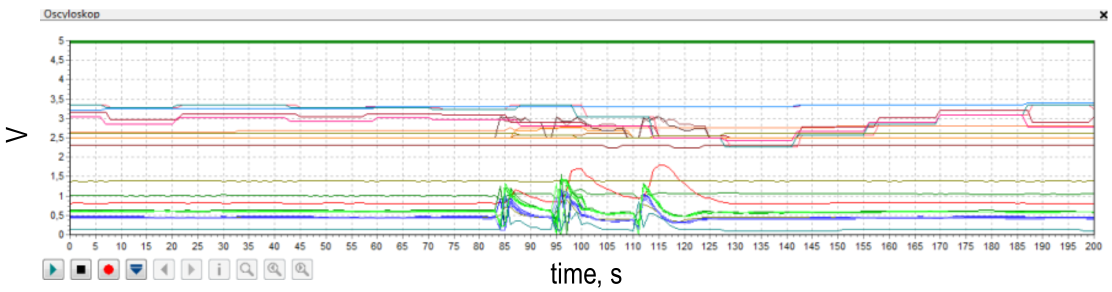


Fig. 3 Presentation of the curves based on the AC STAG software

The values are encoded and retrievable only with the use of a dedicated doftware. For a more in-depth analysis, it is necessary to decode the information and save it as a text file.

4. Results and Discussion

Due to the size of the results, only four urban and extra urban cycles were presented (approx. 42 min. each). In each case, the coolant temperature was greater than 30°C, which ensured switching from gasoline to LPG fueling after approx. 10 seconds from the engine start. The fuel maps were not manually adjusted (Fig. 4). Only small adaptations were introduced by the control module.

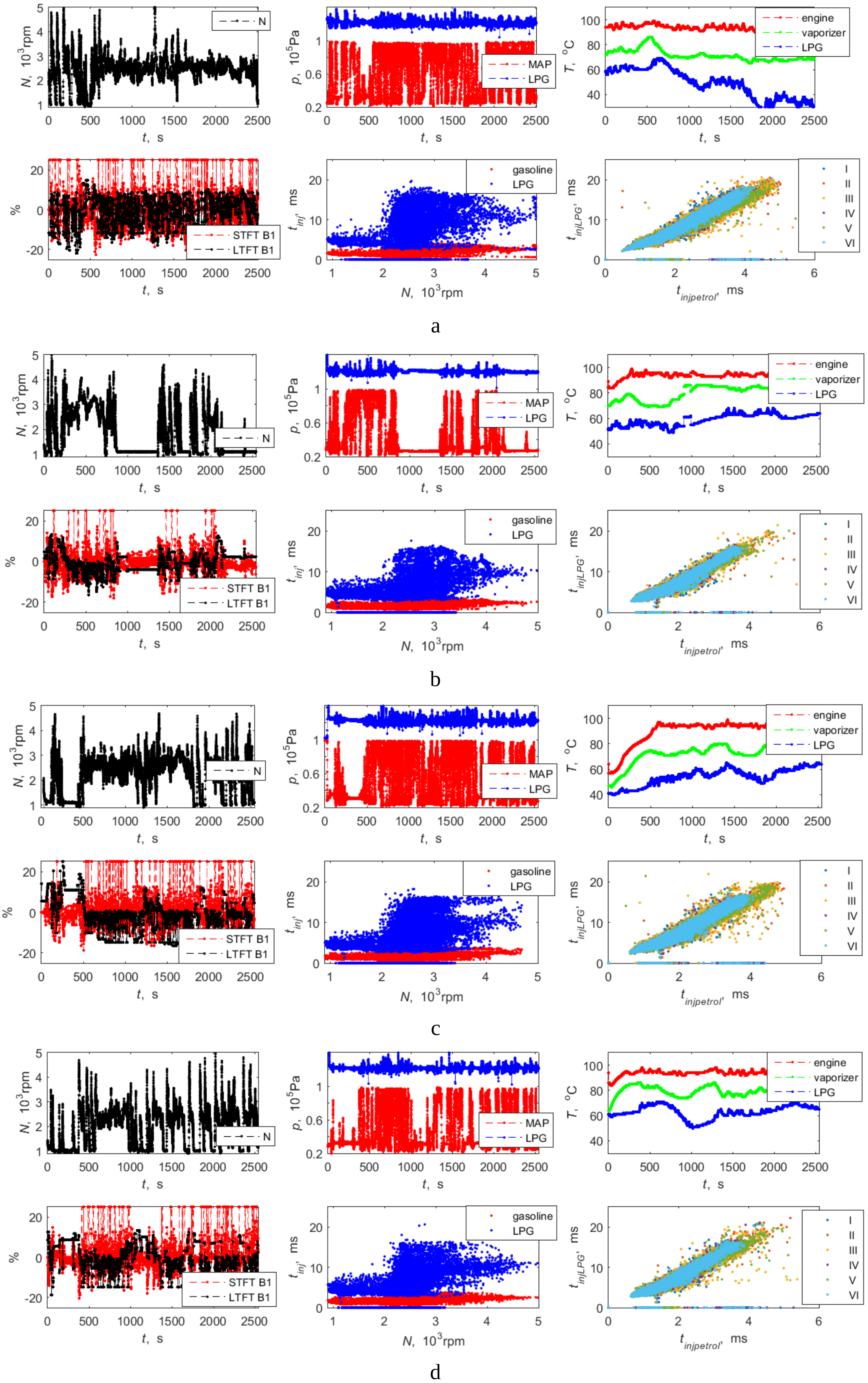


Fig. 4 Examples curves of the LPG fuel system parameters under analysis

In all of the cycles (Fig. 4a, b, c and d) the maximum engine speed did not exceed 5000 rpm. The vehicle drivetrain was equipped with an automatic transmission, which is why the load values were similar. Comparing the MAP and LPG pressures, one can see a correct operation of the vapor LPG regulator. The 1.2 bar overpressure was maintained throughout each cycle. The LPG vapor injectors also operated at similar opening times in each of the variants under analysis. The operation of the injectors was defined by the fuel map (Fig. 4). The injection time t_{injLPG} rarely exceeded 20 ms, which prevented the system against 'overlapping' injections (continuous opening). The final validation of the LPG system operation was the evaluation of the short term (STFT B1) and long-term (LTFT B1) fuel trims. In this case one could see clear oscillations of the STFT up to the boundary values ±25%, which indicates certain imperfections of the LPG vapor injectors. The LPG was injected in its vapor phase, whose volume is approx. 300 greater compared to gasoline [6]. The injectors have heavier actuators, hence the longer opening and closing times, lower accuracy and repeatability [7]. The LTFT (±15%) indicated that, in the long run, the STFT oscillations did not affect the adaptation of the engine control. No engine error codes were detected related to the LPG fueling during the investigations.

5. Conclusions

The application of alternative fuels in transport is some sort of a challenge, particularly in the case of modern engines. Naturally aspirated engines of older generation utilizing multipoint indirect injection are easily convertible to vapor phase LPG fueling. In the paper, the author attempted to evaluate the operation of an LPG vapor phase fuel system under the conditions of non-standardized driving. This kind of methodology was adopted due to low adequacy of laboratory research (driving cycles) to the actual conditions of vehicle operation. During the analysis of the operating parameters of the LPG vapor phase fuel system, no significant malfunctions were observed. The system operated correctly despite the assumption that this was a universal solution possible to fit in other types of vehicles of similar power output. The tests confirmed the applicability of the data recorders supplied by the LPG system manufacturer for the assessment of the correctness of operation.

Acknowledgment

The research has been carried out within work no. S/WM/1/2018 realized at Bialystok University of Technology and financed from the funding allocated for science by the Ministry of Science and Higher Education – Poland.

References

1. **Raslavičius, L.; Keršys, A.; Mockus, S.; Keršienė, N.; Starevičius, M.** 2014. Liquefied petroleum gas (LPG) as a medium-term option in the transition to sustainable fuels and transport, Renewable & Sustainable Energy Reviews 32: 513-525. http://dx.doi.org /10.1016/j.rser.2014.01.052.
2. **Wendeker, M.; Jaklinski. P.; Czarnigowski. J.; Boulet. P.; Breaban. F.** 2007. Operational parameters of LPG fuelled SI engine – comparison of simultaneous and sequential port injection, SAE Technical Paper 2007-01-2051. http://dx.doi.org/10.4271/2007-01-2051.
3. **Borawski, A.** 2015. Modification of a fourth generation LPG installation improving the power supply to a spark ignition engine, Eksploatacja i Niezawodnosc - Maintenance and Reliability 17(1): 1-6. http://dx.doi.org/10.17531/ein.2015.1.1.
4. **Szpica, D.; Czaban J.** 2014. Operational assessment of selected gasoline and LPG vapour injector dosage regularity, Mechanika 20(5): 480-488. http://dx.doi.org/10.5755/j01.mech.20.5.7780.
5. **Czaban, J.; Szpica, D.** 2013. Drive test system to be used on roller dynamometer, Mechanika 19(5): 600-605. http://dx.doi.org/10.5755/j01.mech.19.5.5542.
6. **Duk, M.; Czarnigowski, J.; Jakliński, P.; Zyska, T.; Iskakova, A.** 2014. Badania eksperymentalne wpływu wypełnienia sygnału sterującego na czas wyłączania impulsowego wtrysku gazu, Przeglad Elektrotechniczny 90(3): 199-202. http://dx.doi.org/10.12915/pe.2014.03.45.
7. **Szpica, D.** 2018. Investigating fuel dosage non-repeatability of low pressure gas-phase injectors, Flow Measurement and Instrumentation 59: 147-156. https://doi.org/10.1016/j.flowmeasinst.2017.12.009.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Analysis of Stress Distribution of Tracked Vehicle Torsion Bar

Q. H. Nguyen[1], J. Furch[2]

[1]*University of Defence, Kounicova 65, 66210 Brno, Czech Republic, E-mail:* quyhung.nguyen@unob.cz
[2]*University of Defence, Kounicova 65, 66210 Brno, Czech Republic, E-mail:* jan.furch@unob.cz

Abstract

Torsion bars are the crucial elements of a vehicle suspension system. This paper demonstrates the analysis of the stress distribution of the torsion bar of a tracked vehicle. A virtual model of the tracked vehicle based on the Adams/ATV with modified suspension is used. The loads on road wheels of the suspension are obtained through dynamic analyses of the whole vehicle. Stress distribution of the torsion bar under dynamic loads is acquired by Adams Durability. The model can be used to optimize the characteristics of tracked vehicle suspension, detect hot spots in flexible bodies, and improve component design.
KEY WORDS: *tracked vehicle model, suspension model, torsion bar, MSC.ADAMS*

1. Introduction

Suspension of tracked vehicles plays an essential role in the stabilization of the hull, providing ride comfort and firing accuracy. Due to the large mass of the vehicle, the optimization of the suspension makes it difficult to balance the softness required by the ride comfort incentives with the rigidity required by a firm position of the hull and the rapid dissipation of the hull oscillations.

Military tracked vehicles are designed for movement in a heavy terrain. Movement in such a terrain increases requirements on chassis and propulsion mechanism. Particularly suspension system is highly loaded with dynamic stress which originated from movement on rough and bumpy terrain [1].

Analysis of the stress of the suspension system is indispensable for development and evaluation of a new suspension system in process of vehicle modernization in which vehicle gains weight. Stress analysis is a great way of ensuring the product reliability.

2. Model of a Tracked Vehicle

The majority of military tracked vehicles use torsion bar independent suspensions. The running gear of such type of vehicles is shown in Figs. 1-2.

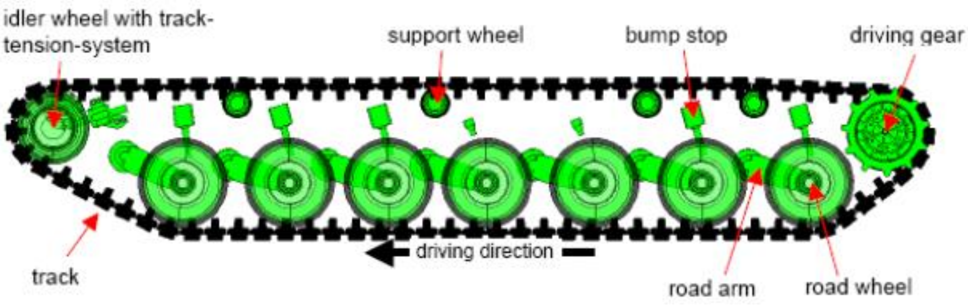


Fig. 1 Tracked vehicle running gear [2]

Fig. 2 Model of a torsion bar suspension assembly

The whole assumed tracked vehicle model is established based on the tracked vehicle's special module Adams/ATV, which consisted of the hull, two track systems on both sides and the roadway. The track system of the half model is composed of idler wheel, drive sprocket, five road wheels, support roller and 73 links of track belt. Drive sprocket is located at the rear of the vehicle [3]. Created model is shown in the Fig. 3.

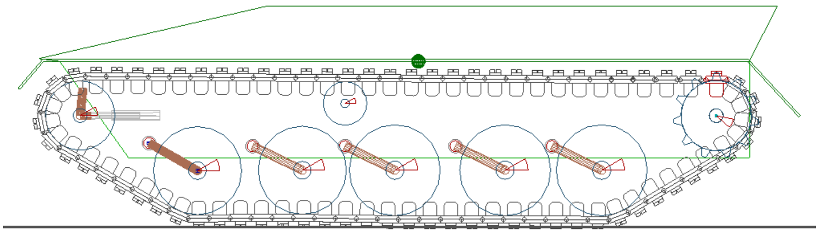


Fig. 3 Model of the tracked vehicle

Adams/ATV is used to carry out dynamic analyses of tracked vehicle and Adams Durability is utilized to get stress on suspension component. Adams Durability is a part of the Adams 2017® suite which enables to perform stress recovery of flexible bodies. Flexible parts are created in Adams Flex by swap rigid bodies with flexible bodies.

In Adams/ATV, the torsion bar is represented by a rotational spring element that defines a torque-displacement (rotation angle) relationship between road wheel arm and the hull of the tracked vehicle. The spring torque acts on road wheel arm and the hull of the vehicle. The torque equation of a linear rotational spring [4]:

$$T = T_0 - K\left(\beta - \beta_0\right), \tag{1}$$

where T - spring torque; T_0 - spring torque preload; K - linear stiffness of the spring; β - instantaneous angle; β_0 - angle at which the torque preload is given.

For the circular section torsion shaft, the shear stress at any point at distance r from the axis of rotation is defined [5]:

$$\tau = \frac{Tr}{J} = \frac{G\theta r}{l}, \tag{2}$$

where τ - shear stress of the shaft; T - torque applied; r - radiant distance to center of the shaft; J - polar moment of inertia; G - modulus of rigidity (shear modulus); θ - angle of twist; l - length of the shaft.

3. Dynamic Analysis of Tracked Vehicle

A dynamic tracked vehicle simulation is carried out to actuate the rotational spring across a range of terrain profiles. The analysis is focused on the stress of suspension mechanism and influence of different profiles of the terrain on the character of the suspension stress.

Experience in the operation of high speed tracked vehicles shows that the worst from the point of view of ride comfort is under a periodic disturbance [6], [7]. Therefore, if the vehicle moves along regularly undulating terrain with constant speed, the periodic profile of the vehicle path will correspond to the periodic excitation. The movement in these sections at a certain speed is the most difficult from the point of view of ride comfort.

The wavelength a of the road profile which is the most dangerous according to the rebound of the suspension is within interval:

$$L < a < 2.5\,L, \tag{3}$$

where L is the distance between the axes of the outer road wheels of the vehicle.

During simulation two terrain profiles are used: the flat road and the sinusoidal terrain with height 10 cm, spacing 6.3 m.

Speed is constant at 20 kmh^{-1} for all terrains. Initial velocity is 0 kmh^{-1}. Simulation time is set to 6.0 s.

4. Results

Torque and stress of the spring of road wheels are traced during simulation. They are presented and compared in the following graphs (Figs. 4-11).

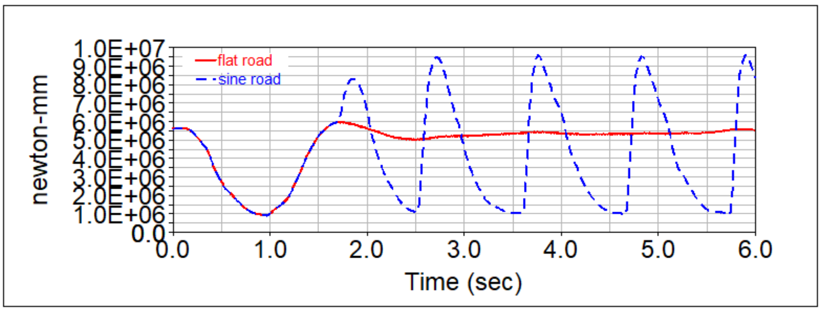


Fig. 4 Torque of the 1st road wheel

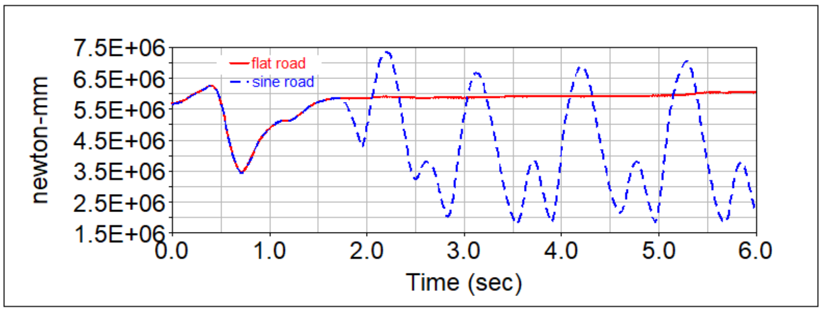


Fig. 5 Torque of the 3th road wheel

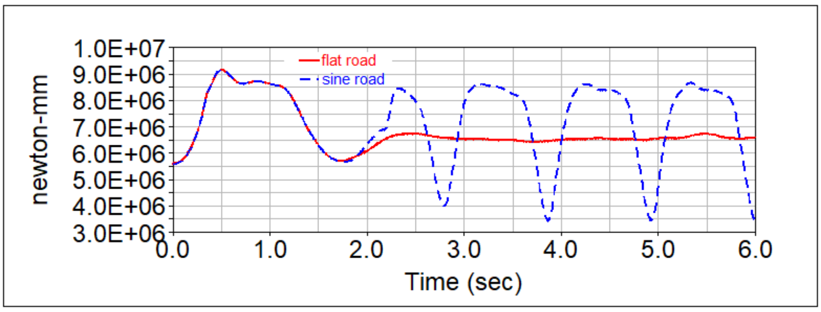


Fig. 6 Torque of the 5th road wheel

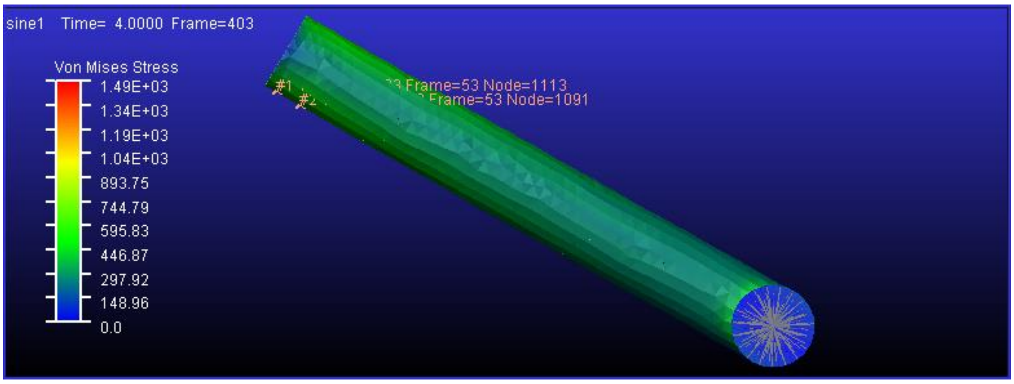


Fig. 7 Stress of the 1st road wheel on sinusoidal road

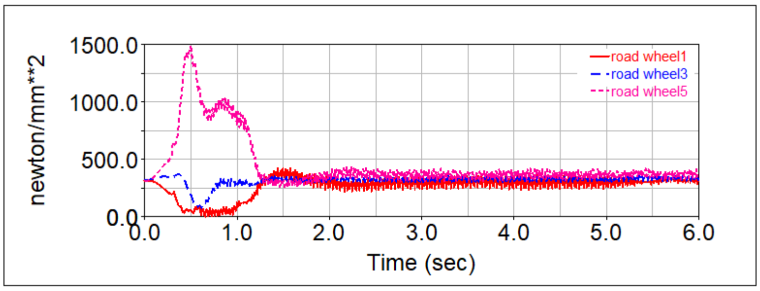


Fig. 8 Stress of road wheels, flat road

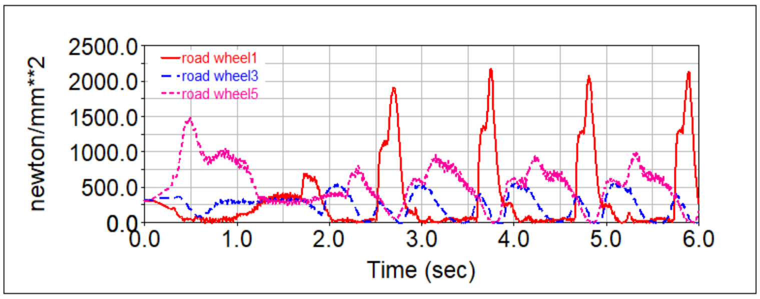


Fig. 9 Stress of road wheels, sinusoidal road

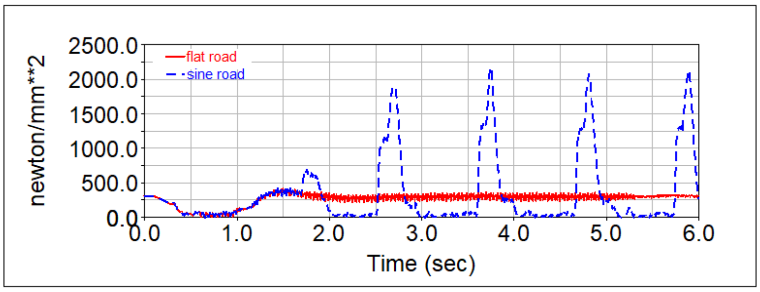


Fig. 10 Stress of the 1st road wheels

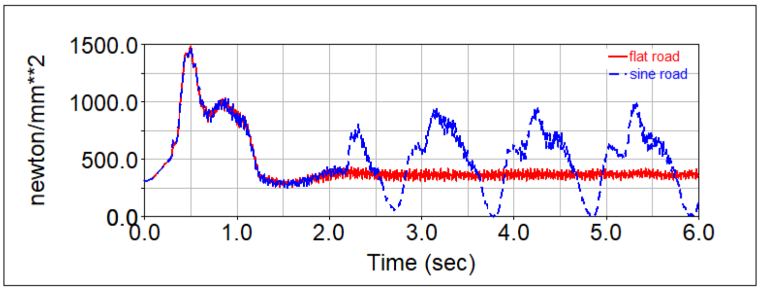


Fig. 11 Stress of the 5st road wheels

The plots show that on a flat road, vehicle has stabilized vibration with small magnitude. The torque and stress also change with small scale except at the beginning of the move corresponding starting of the vehicle. The torque and stress of the 5th road wheel have the maximum value.

On the sinusoidal road, torque and stress change periodically corresponding to the terrain profile with greater magnitude. The maximum value is found at the 1st road wheel.

Table

Von Mises hot spots for flex bodies

Road wheel	Flat road	Sine road
1	423.5	2185.8
2	368.7	730.9
3	376.0	564.9
4	568.8	831.1
5	1486.2	1489.6

Table shows the Von Mises hot spots in the road wheel springs. It can be seen from Table that the 1st road wheel has the highest magnitude on the sinusoidal road as it exposes to bumps on the road. Thus it is recommended to increase the damping of the front road wheels.

5. Conclusions

Chassis of track vehicle is a complicated mechanism and it is difficult to sufficiently analyze suspension mechanism by mathematical methods. Simulating technology take an advantage for analysis of suspension mechanism, for vehicle movement analysis and for analysis of the stress of the main parts of the chassis.

Adams/ATV, Adams Durability are utilized to build the model, analyze the suspension of a tracked vehicle and obtain the stress on suspension. Simulation results illustrate that the 1st road wheel has the maximum stress when a

tracked vehicle moves on a sinusoidal road.

The model can be used to optimize the characteristics of tracked vehicle suspension and improve component design.

Acknowledgment

Presented work has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development and Specific Research, Department of Combat and Special Vehicles, University of Defence, Brno.

References

1. **Neumann, V.** 2014. Analysis of a Load of a Tracked Vehicle Suspension System, Transport Means: 457-460.
2. **Ciobotaru, T.; Vinturis, V.** 2009. Methods for the calculus of the road wheel vertical load, COMEC: 139-144.
3. **Wang, H.; Rui, Q.; He, X.** 2007. The prediction technology study of fatigue life for key parts of a tracked vehicle's suspension system, Front. Mech. Eng. China 2(1): 68-71.
4. MSC.Adams 2017. Adams Tracked Vehicle Toolkit.
5. **Sardagi1, R.; Panditrao, K.** 2014. Design and Optimization of Passenger Car Torsion Bar [online cit.: 2018-05-10]. Available from: http://www.iosrjournals.org/iosr-jmce/papers/ICAET-2014/me/volume-3/4.pdf
6. **Sergeev, L.** 1973. Theory of tank. Moscow: Publishing of Tank-Armoured Academy, 493 p. (in Russian).
7. **Novotný, P.; Prokop, A.; Zubík, M.; Řehák, K**. 2016. Investigating the influence of computational model complexity on noise and vibration modeling of powertrain, Journal of Vibroengineering, 18(1): 378–393.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Effectiveness Evaluation of International Railway Transportation in the Direction of “Ukraine – European Union”

M. Kurhan[1], D. Kurhan[2]

[1]*Dnipropetrovsk National University of Railway Transport named after academician V. Lazaryana, ac.Lazaryana str, 2, 49010, Dnipro,Ukraine, E-mail: kunibor@gmail.com*
[2]*Dnipropetrovsk National University of Railway Transport named after academician V. Lazaryana, ac. Lazaryana str, 2, 49010, Dnipro,Ukraine, E-mail: kurhan.d@gmail.com*

Abstract

The paper presents results of a study concerning the development of railway transit traffic in international transport. It identifies problematic issues at the border crossing in the direction of "Ukraine–European Union" and ways to eliminate them. During the research methods of analysis and synthesis were used to study statistical materials and the main provisions of scientific papers about the state and prospects for the development of European and domestic systems of international railway transportation. In order to predict the volume of international transportation, the experience of creating, operating and optimizing systems including international transport corridors, rolling stock and border station technology at the rail gauge joint of different standards (1435/1520 mm) are taken into account.
KEY WORDS: *international railway transportation, transport corridors, track gauge change, dual gauge*

1. Introduction

The economic development of each state largely depends on the operation of the transport system, which should ensure reliable, safe and efficient operation of freight transport both inside the country and abroad. How relevant issues of interstate transportation one can judge from the materials published by the Committee of Organization for the Collaboration of Railways. The OSJD Journal [1] discussed such issues as facilitation of border crossing procedures by railway transport, the experience of railways in accelerating the passing of borders during international railway transportation in the Eurasian space, and others.

The geographic scope of the OSJD covers more than 280 thousand km of railway lines from 28 countries of the world, on the railways of which about 6 billion tons of cargo and more than 4 billion passengers are transported annually. Naturally, on this space, the improvement of international railway transportation plays a not insignificant role for the successful providing of railway transportation with a focus on reducing the time for passing trains through interstate borders.

The possibilities of railway transport for the organization of transportation between the countries of the European Union (EU) and Ukraine are not fully exploited, since there are a number of technical reasons for the incompatibility of transport systems, namely: different wheel gauge, rolling stock characteristics, type of signaling arrangement (SA), voltage in the contact network, dimensions and suchlike.

Future prospects for the integration of Ukraine's railways into the European transport network will depend on how successfully the tasks on the actual development of international transport corridors (ITC) will be solved, on the availability of rolling stock ready to provide transport with governed speeds [2, 3], on political-economic and technical-technological problems of passenger turnover [4] and truck turn-around between Ukraine and Europe.

Cargo transportation via the ITC can be carried out both with the use of one mode of transport (unimodal transportation) or various types (multimodal transportation).

The main vectors of modern geospatial relations of Ukraine: Poland - the EU countries; Belarus - the Baltic countries; Georgia - the countries of Central Asia and Transcaucasia; Turkey - the countries of the eastern Mediterranean, etc. The growth of EU trade with China, India and other countries contributes to the sustainable development, first of all, railway transportation in the international communication "Ukraine-EU".

In connection with the intensive development of the Ukraine's railway transport integration processes in the European transport system, the following issues are of great importance: the functioning of international transport corridors (ITC), the introduction of specialized rolling stock into the turnover that would allow operation both on the European gauge track of 1435 mm and on Wide-gauge track of 1520 mm, that is, the application of European ASCS-technologies based on automated track joint systems of 1520/1435 mm, creating the "East-West" cars for transferring goods without any transshipment by railways of different standards.

2. Options of Cargo Delivery in International Traffic

The rolling stock, used for international transportation, has a principal role in ensuring the technical and technological transportation of passengers and cargoes by international transport corridors via division points of railways,

gauges of 1520 mm and 1435 mm. At the same time, the task of choosing a rational technology for the operation of border stations for the transfer of cars from a wheel gauge of 1435 mm to a wheel gauge of 1520 mm and in the opposite direction, which requires a scientific substantiation of the process of servicing the car traffic volume by determining the optimal term for cars location at stations connecting tracks of different widths and costs of monetary resources in the logistics chain of international cargo delivery.

Analysis of the organizational mode for the cargo transportation in international traffic with the EU countries showed that the following options are subject to comparison:

2.1. Transshipment of Cargo, Including in Containers with a Rolling Stock, Gauge of 1520 mm to a Rolling Stock, Gauge of 1435 mm

Until now, the railway communication between Ukraine and the EU countries is provided by the use of obsolete technologies, which are based on cargo transshipment and the undercarriage replacement. In these technologies, neither locomotives nor cars are on the way to the European standard [2].

The need for cargo transshipment arises when the change of the railway track width or when the transport mode change depending on the transportation schemes. At the same time, transshipment can take place on a direct option - from one rolling stock to another, and with placement in temporary warehouses with the further loading into another rolling stock.

2.2. Replacement of Bogies at Cars Transposition Stations (CTS) at the Transition of Track Joint of Different Standards

Railway transportation along lines with different wheel gauges causes certain problems at the division points, which increases the duration and cost of transportation. The most common way of transferring goods without any transshipment to the railways of neighboring countries, having different wheel gauges, is the change of bogies in the cars at the border station. Domestic cars can be delivered on the bogies, wheel gauges of 1435 mm if they meet the technical requirements of adjacent railways (dimensions of cars, braking system, load from the axis of cars to rails). Cars of European railways, wheel gauges of 1435 mm with imported cargo are not replaced to bogies, wheel gauges of 1520 mm due to technical discrepancy of their construction to the requirements imposed to cars by the rules of technical operation for domestic roads.

2.3. Application of the special rolling stock equipped with bogies with sliding set wheels

The main issue that remains open at present is the use of an automatic changeover system by the rolling-stock from a gauge of one width to another under the common name AGCS (Automatic Gauge Changeover Systems), which removes the real limitation of interoperability.

Prospects for the wide implementation of AGCS systems associated with the development of international transport corridors. The following directions are suggested as priority: the Baltic Sea - the Black Sea (a component of the "Baltic-Black Sea Axis" project); Ukraine - Poland - Germany; Ukraine - Hungary - Slovenia - Italy; Ukraine - Slovak - Austria / Czech Republic. The last two corridors from Ukraine are a natural continuation of the corridors of the trans-European transport TEN-T network, namely the corridors Rhine-Danube Coridor s Mediterranean Corridor.

In the European railway practice, several automatic changeover systems of cars from one gauge to another are known, which have been brought to practical use: TALGO, BRAVA (Spain), a Bulgarian-made BT system, the Polish SUW 2000 system, DB AG / Rafil Typ V (Germany). The principle of operation is similar to the wheel set of the SUW 2000 system [5] and allows using the same track-reverse device.

2.4. Construction (use of existing) wide gauge, 1520 mm from the borders of Ukraine to the territory of Europe

The idea of continuing the wide gauge to the countries of Central Europe was first announced at the end of June 2001, when Ukraine signed a memorandum concerning the participation in the intercontinental transport project of the century and justified its proposal on the railway passing through Ukraine and Poland to the Czech Bohumín city. The construction of the railway through Ukraine would take only 2 years, since a railway gauge of 1520 mm has already been laid and used in the Volyn region almost to Katowice.

Secondly, the idea of continuing a wide gauge to the countries of Central Europe was publicly announced in May 2006 during the international forum "Strategic Partnership 1520". This is a promising international project for the construction of the Kosice-Bratislava-Vienna wide-gauge railway line (the Eurasian Railway Corridor). The project envisages both the construction of a new railway and the reconstruction of the existing, direction Lviv-Chop Cretan No. 5 (Triest-Ljubljana-Budapest-Bratislava-Uzhhorod-Lviv).

The commissioning of a wide gauge to Vienna will significantly increase the flow of cargo transit through the territory of Ukraine. According to preliminary calculations, traffic volumes will be at least 30-40 million tons per year. The implementation of this project will make it possible to reduce the cost of transit cargo transportation by railway, so the cost for cargo loading and unloading in the border area is excluded.

Today, the longest section of the railway with a gauge of 1520 mm is used in Poland - about 395 km (Izow-

Hrubieszow-Slavkov) and in Slovakia - about 90 km (Uzhgorod-Kosice). In the direction of Hrubieszów there is an export, and in Slavkov there is an import. More than 50% of the cargoes transported to Slavkov are iron ore. Coke and coal mainly are transported back to the east.

2.5. Continuation of European gauge of 1435 mm from the borders of Europe to the territory of Ukraine

Continuation of European gauge of 1435 mm from the borders of Europe to the territory of Ukraine can take place in the case of constant mass volumes of traffic during reloading-free technologies by entering the railroad track of the importing state into the territory of the exporting state.

In Ukraine, there is already experience of using the European gauge. Thus, trains from Slovakia to Romania pass through the European gauge on the Ukrainian territory (Chop, Batevo, Korolevo, Dyakovo) without changing of wheel sets. The longest railroad section, gauge of 1435 mm, used on the territory of Ukraine - 112 km (Chop-Dyakovo). Ukraine and Hungary are considering the possibility of putting on the Mukachevo-Budapest train on the European gauge, which will save a lot of time for tourists [6].

As an example of such technology usage are the Baltic countries. One of the priority railway projects in Europe is the railway "Rail Baltica" (Fig. 1), it is a part of the railway corridor "North Sea-Baltic", which connects Finland, Estonia, Latvia, Lithuania, Poland, Germany, Holland, Belgium and Luxembourg. The length of the "North Sea-Baltic" corridor is 3200 kilometers. The major objective of Rail Baltica is the resumption of direct communication between the Baltic States and the European railway network and the development of regional integration. Integration of the railways in Estonia, Latvia and Lithuania into the transport system of the European Union will allow increasing the speed of train traffic, growth of passenger and freight traffic and profits [8, 9].

According to the project, the highway will pass through Tallinn, Riga, Kaunas, Warsaw and Berlin (and further - the continuation of the route to Venice), thus improving the communication between Central and Eastern Europe.

2.6. Use of the Dual Gauge 1435/1520 mm

At Lviv railway, the total length of the dual railway track (1520 and 1435 mm) is about 150 km. This line is laid on the sections: the State Border - Mostiska 2 - Rodatichi, the State Border - Chop-Batevo, the State Border - Yagodin - Kovel, etc. These sections are included in the international transport corridors (Cretan No. 3, No. 5 and Gdansk-Odesa).

Fig. 1 Railway «Rail Baltica» [7]

Fig. 2 Dual gauge at the section Shyashtokai - Mockava [7]

As an example of using the dual gauge is the international project "Rail Baltica" from the state border of Lithuania and Poland to Kaunas (Fig. 2). A new gauge of the European standard (width of 1435 mm) was laid on the railroad section "Rail Baltica" with a length of 120 km, and next to it the existing railway line of the Russian standard (1520 mm) was renovated. On the new route 233 km of new rails for tracks with a wheel gauge of 1435 mm and 1520 mm were laid, including track parks at the stations, the infrastructure of railway engineering networks was updated, stations were reconstructed.

In October 2015, the first section of the railway was laid, and from June 17, 2016, a regular passenger service from Kaunas (Lithuania) to Belostok (Poland) was opened.

The main disadvantage of the dual gauge is that it requires junctions and bypasses of separate points due to the need to lay off the turnouts for normal 1520 mm gauge and European 1,435 mm one, which leads to a decrease in the speed of the trains when passing stations.

3. The Model for Predicting and Evaluating the Effectiveness of Options

The following major principles are base in the evaluating the effectiveness of the project: consideration of the option (project) throughout the calculation period, positivity and maximum effect, time factor record, the inflation im-

pact, uncertainty, risks, and suchlike. According to the methodology of the United Nations (UNIDO), the evaluation can be carried out according to the following indicators:

– net present value of NPV (Net Present Value of Discounted Cash is the difference between total income and all types –Flow) costs, taking into account the time factor. Discounting of monetary expenses is carried out by multiplying them on the discount factor;

– internal rate of return IRR (Internal Rate of Return) is defined as the annual coefficient of capital investments, which ensures that the costs and incomes for the "life" term of the investment are equal to zero. The project is considered to be effective if the IRR is not lower than stable bank rates;

– pay-back period of capital investments PBP (Pay-Back Period) represents the payback period, during which the income minus operating costs (functional and administrative) reimburses the basic capital investments; this is the most positive net present value;

– maximum cash outflow (Cash Outflow).

To compare the above options, the authors developed a model for predicting and evaluating the efficiency of railway transportation in accordance with the scheme: the consignor–crossing the border with different wheel gauge–the consignee taking into account all expenses upon the NPV indicator, which is the difference between the total income and all types of costs, considering the time factor , (investments, expenses for the locomotive fleet and car fleet, current operating costs and expenses, depending on the type of technological operations and the time of the freight cars location at the joint stations for tracks of different width (according to options 2.1-2.6).

Uncertainty and risks in evaluating the effectiveness of options were taken into account through a modified discount rate, which is included in the calculation of the discount factor for different-time expenses.

To determine the transportation charges, the International Railway Transit Tariff (IRTT) was used, which is applied for the shipment of cargo, as well as for transportation through border and port stations [10].

From the analysis of tariffs it follows that the fee is determined depending on the distance of transportation, and the highest growth rate of payment (on average by 10% for every 100 km) is observed at distances of up to 1000 km and only 0.5% at long distances. This has a significant effect on the final result. The description of the model is presented in the paper [11].

The developed model allows investigating and predicting the revenues that PJCC "Ukrzaliznytsia" will receive from transportation in case of applying each of the above six options for various levels of prediction: optimistic, pessimistic, medium (intermediate).

4. Findings

At present, on the order of Ukrzaliznytsya, Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan (DNURT) performs the research project "Scientific and technical support for the sustainable development of railway transportations in the international communication "Ukraine-EU" within the framework of which methodical approaches to the determining the rational ways for rolling stock changeover from a wide Ukrainian gauge of 1520 mm to the European gauge of 1435 mm for transit transportation service were developed [12].

In modeling, the initial volumes of traffic and the rate of their growth over time, the distance of transportation, the type of cargo and cars for transportation, delivery speed that depended on the state of the railway infrastructure on international transport corridors were fluctuated.

Below there are results of studies on the use of the existing or construction of a new wide gauge of 1520 mm from the borders of Ukraine to the territory of Europe to the established terminal.

If we consider the cargo transportation through Ukraine and the construction of a new wide gauge, then from Figure 3 it follows that such decisions can be considered effective for cargo traffic of at least 25-30 million tons per year. With the indicated volumes of traffic, the profit from transportation (ie NPV > 0) comes in the 3rd year if the length of the new railway being built is 25% of the total length, in the 6th year, with a specific weight of the new railway of 50%, in the 10th year - with a specific weight of 75% and beyond the 15th year, if the new railway is built completely, i.e. 100%.

If the specific weight of the new line is 50% of the total length of 1000 km, NPV > 0 occurs in the 6th year with a cargo traffic of G = 30 million tons/year, in the 5th year at G = 35 million tons/year and about 4th year at G = 40 million tons/year. So, the greater the volume of transportations, the earlier the costs of the construction of the new wide gauge line pay for itself, and the earlier Ukrzaliznytsia will receive traffic income.

Obviously, the greater the specific weight of the new railway wide gauge from the total length of the direction, the later the construction costs pay for itself and the later incomes from transportations will be received. Thus, according to the analysis of variant calculations, assuming NPV = 0 and the cargo traffic G = 30 million tons/year the timeframe will be as follows: with the specific weight of the new line 25% - 3d year, 50% - year 7th year, 75% - about 10th year, and at 100% – beyond the 15th year. At G = 40 million tons/year, respectively, the 2nd, 5th, 7th and 10th years.

It should be noted that the influence of the specific weight of the new railway will be different, depending on the total length of the direction. Thus, with the cargo traffic of 30 million tons/year, the income from transportation with a specific weight of the new railway of 50% in the total length of the direction of 1000 km comes in the 6th year, with a length of 1500 km in the 13th year, and with a longer length beyond the 15th year.

Costs for construction of the new railway have a great impact in obtaining positive results. As an example, two

options are considered when the construction conditions are easy and the cost of 1 km is 10 million euros (Fig. 4) and complex conditions, the cost of 1 km is 20 million euros. In the first case, it is possible to expect incomes from transportation only if the transportation distances are less than 1600 km, in the second case - at a length less than 900 km.

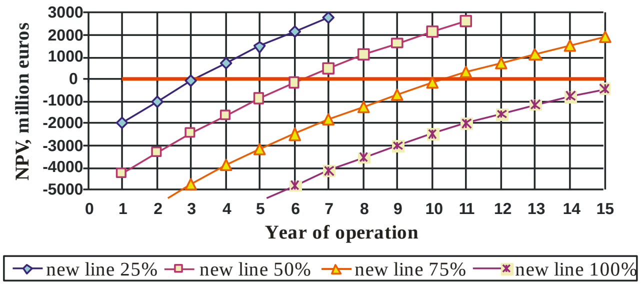


Fig. 3 The dependence of NPV on the specific weight of the new line in the total length of the route

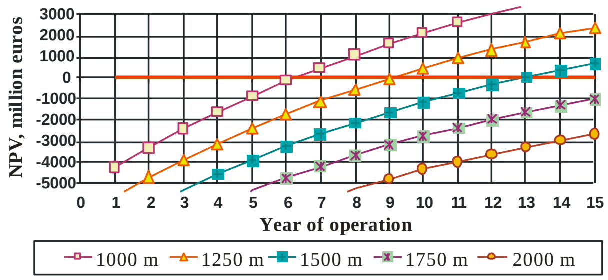


Fig. 4 Dependence on the length of haul at a cost of 1 km of the new line construction 10 million euros

The income from transportation with a specific weight of the new railway of 50% in the total length, direction of 1000 km comes at a construction cost of 10 million euro/km with the cargo traffic of 15 million ton/year. At the cost of 15 million euro/km – with the cargo traffic of 23 million tons/year, at a cost of 20 million euros/year – with a cargo traffic of 30 million tons/year (Fig. 5). At the direction length of 2000 km, respectively, at 20th, 28th and 38th million tons/year.

To study the schedule speed impact on the change in net present value, calculations were made for the section, length of 1000 km (Fig. 6).

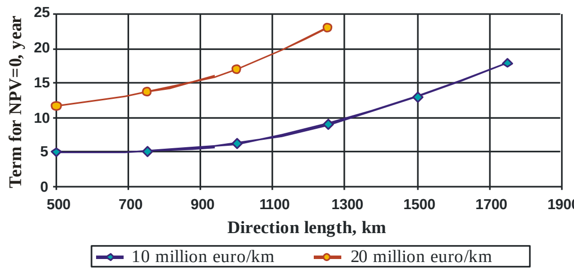


Fig. 5 The term for appearance of incomes from transportation, depending on the cargo transportation length at a specific weight of the new line of 50% and a different cost of construction

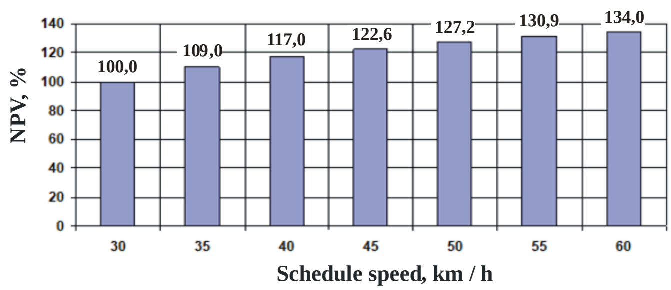


Fig. 6 Change in the net present value depending on the schedule speed

5. Conclusions

The results obtained in the paper allow us to conclude that international transportation, which is carried out through the territory of Ukraine, has a number of peculiarities. The change in railway standards on the border with European countries makes it necessary to search for the most rational routes for cargo transporting, taking into account the length, technical condition and parameters of ITC, speed of delivery, etc.). And rational technologies for the transferring goods without any transshipment at border stations; this will make it possible to propel these transportations to an innovative way of development. There are known ways of reloading goods, changing the bogies of cars to WPV, application of rolling stock with sliding wheel sets, as well as existing and new projects for continuation of the wide gauge to Europe and European gauge implementation in Ukraine have a certain scope. The methodological approaches and the developed mathematical model suggested by the authors allow Ukrzaliznytsia to plan, under various scenarios for the cargo traffic movement, measures to accelerate the cargo delivery both in Ukraine and during the transfer of them at border stations and to predict the receipt of incomes from international transportation in the direction of "East-West".

The results of the study made it possible to conclude that it is necessary to carry out measures to modernize the transport corridors in order to increase speed and reduce the time of cargo delivery, which affects the turnover of rolling stock and the number of vehicles and, as a result, to receipt incomes from transportation. Thus, for example, an increase in the schedule speed from 30 up to 40 km/h leads to an increase in NPV by 17%, from 40 up to 50 km/h – by 10%, from 50 up to 60 km/h – by 7%.

The decision in favor of the construction of the wide gauge railroad through the deep input of the railway of the exporting state into the territory of the importing state or the imposition of the European gauge of the importing state on the territory of the exporting country should be made taking into account the direction and volumes of the main cargo traffic (from the east to the west or from the west to the east) and the construction cost of the object. The foregoing follows from these considerations: the options for the construction of a new railway of wide or European gauge require

large investments in infrastructure, and their effectiveness can be confirmed with sufficiently high traffic volumes of transportations (not less than 15-20 million tons per year at a unit cost of 1 km of rail roads 10 million euros, 25-30 million tons/year at a cost of 1 km road 15 million euros and 30-40 million tons/year at a cost of 1 km 20 million euros). The type of cargo and terms of delivery can become decisive. For example, for long terms of cargo delivery to the consignee, rail transportations can become not competitive to automobile transport.

Undoubtedly, not only economic but also social factors must be taken into account for the final decision, as well as the reliability (non-failure operation) of a particular cargo transportation system. This issue is subject to additional research, but even now one can say that the greatest reliability and small delays at the border are provided by options for constructing the wide gauge railroad or European gauge to the appropriate terminals or ports.

References

1. The best practice of increasing the efficiency of international transport in the Eurasian space. Documents and Leaflets of OSJD [online cit.: 2018-03-26]. Available from: http://osjd.org/dbmm/download?vp=51&load=y&col_id=2066&id=1883
2. **Demyn, Ju.V.; Vereshhak, Ju.V.** 2010. Logistics in railway transport. Visnik of the Volodymyr Dahl East Ukrainian National University 5(147): 167-172. (in Russia)
3. **Fischer, S.** 2015. Traction energy consumption of electric locomotives and electric multiple units at speed restrictions. Acta Technica Jaurinensis 8(3): 240-256.
4. **Kurhan, M.B.; Kurhan, D.M.** 2017. Forecasting of Passenger Traffic upon Implementation of High-Speed Running. Science and Transport Progress, Bulletin of Dnipropetrovsk National University of Railway Transport 6(72): 40-48.
5. **Szkoda, M.** 2014. Assessment of reliability, availability and maintainability of rail gauge change systems. Eksploatacja i Niezawodnosc, Maintenance and Reliability 16 (3): 422–432.
6. In Mukacheve will carry the European track [online cit.: 2018-03-26]. Available from: https://ua.igotoworld.com/ru/news/1004_v-mukachevo-provedut-evropeyskuyu-koleyu.htm
7. Rail Baltica [online cit.: 2018-03-26]. Available from: https://lt.wikipedia.org/wiki/Rail_Baltica
8. Rail Baltica Global Project CostBenefit Analysis. 2017. pp. 105-193. [online cit.: 2018-03-26]. Available from: http://www.railbaltica.org/wp-content/uploads/2017/04/RB_CBA_FINAL_REPORT_0405.pdf
9. **Cerniauskaite, L.; Sakalauskas, K.; Massel, A.** 2008. European-standard railway line between Vilnius and Kaunas. Environmental engineering, The 7th International Conference: 1125-1129.
10. International railway transit tariff (Tariff 8100). 2018. Official Edition of OSJD [online cit.: 2018-03-26]. Available from: http://osjd.org/dbmm/download?vp=51&load=y&col_id=2066&id=2910
11. **Kurhan, M.B.; Voznaya, E.V.** 2014. Increased Interoperability in International Rail Towards Austria-Slovakia-Ukraine-Russia, Ukraine Railway 12 (18): 24-33. (in Russia).
12. Scientific and technical support of sustainable development of railway transportation in the international communication "Ukraine-EU". Part I. 2017. Scientific research work 0114U002549. Dnipropetrovsk National University of Railway Transport. 131 p. (in Ukraine).

Modeling of the Operation of a Pneumatic Differential Valve Increasing the Efficiency of Pneumatic Brake Actuation of Road Trains

D. Szpica

Bialystok University of Technology, Faculty of Mechanical Engineering, 45C Wiejska Str., 15-351 Bialystok, Poland, E-mail: d.szpica@pb.edu.pl

Abstract

A mathematical model of a valve was developed whose objective was to boost the efficiency of pneumatic brake actuation. In the mathematical description of the system, the method of lumped volumes was applied and the solutions were sought through a numerical method. The proposed differential valve was compared to the conventional solution indicating an advantage of the former (a significant reduction of the transition process). The topic is of particular importance in the case of long trailers or road trains where, for a variety of reasons, electric control cannot be applied and only pneumatic actuation is available.
KEY WORDS: *air braking system, differential valve, mathematical modeling, simulation*

1. Introduction

Road trains are road tractors coupled with trailers or semi trailers. Due to large distances between the braked axles, such sets encounter issues with the operating responsiveness of the brake actuators. Road trains are most often equipped with pneumatic brake systems controlled pneumatically or electrically. In the first case, synchronization and boosting the operating responsiveness (particularly for sudden brakes) are the key factors. In the second case, only electrical connections are required for the control of the electro-valves that are much faster in operation than the pneumatic solutions [1]. There are many methods of improvement of the operating responsiveness of pneumatic brake systems [2, 3], some of which are:

– selection of commensurate diameters of the pneumatic lines;
– application of pneumatic equipment of sufficient valve diameter;
– fitment of an additional acceleration valve in long brake lines;
– application of a variety of adjustment devices including differential ones.

According to the ECE standards [4], the time of pressure increment in all actuators of a road train until it reaches 0.75 p_{max} should not exceed 0.6 s.

2. The Application of Sequential Devices for the Improvement of the Operating Responsiveness of a Brake System

The control theory mentions adjustment devices applied mainly to improve the stability of the regulators without deteriorating the control accuracy. In [2], an application was proposed of differential valves in pneumatic systems of long road trains (Fig. 1).

When the control pedal is depressed slowly the differential device remains inoperative, because the pressures in chambers *A* and *B* (Fig. 1) have sufficient time to equalize. When the pedal is depressed rapidly (emergency braking), the pressure difference in chambers *A* and *B* results in the piston downside displacement in a short time and switching to the pressure feed from line *6* valve *5*. In line *6*, maximum pressure occurs, which increases the piston rod (3) displacement velocity. When the brake pedal is depressed rapidly, the responsiveness of the system fitted with a differential valve increases. Having an increase in the pressure in valve *1* (p_1 in Fig. 1, c) in the system without the differential valve (Fig. 1, a), the pressure on the piston rod *3* increases according to p_3. If the system is fitted with a differential valve (Fig. 1, b), the pressure on the piston rod will increase according to $p`_3$. This is obtained for the same p_1 pressure increment rate at the outlet of the regulation valve *1*.

The analysis shows that the quick responsiveness of the actuator - more precisely - the difference $t_2 - t_3$ (Fig. 1, c) heavily depends on the length and the diameter of the lines as well as the flow capacity of the connection of chambers *A* and *B* (Fig. 1, d). When the braking is slow and chambers *A* and *B* have sufficient time to equalize pressures, lines *2* and *7* (Fig. 1, b) remain connected because the differential valve is inactive. As a consequence, during slow braking, the proportionality is preserved (tracking action) in the drive between the force applied on the pedal and the pressure on the piston rods.

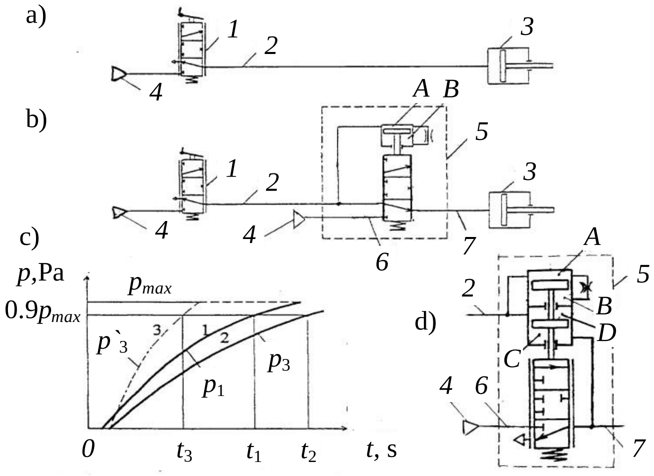


Fig. 1 The schematics of the simplest pneumatic drives [2]: a - a simple circuit with an adjustment valve *1*; b - circuit with a differential valve *5*; c - approximated dynamic characteristics (p_3 and $p`_3$ - of the pressure on the piston rod *3* of the system without valve 5 and with valve *5*); d - schematics of the valve composed of the differentiating device and a proportional valve; *2*, *6* and *7* – line; *4* - source of pressure; A, D, C and D – chambers of the differential valve *5*

3. Mathematical Modeling

For the mathematical description, an isentropic flow in an adiabatic shield was adopted (Fig. 2). Using the lumped elements method [2, 5, 6] the pressure change in the measurement tank based on the mass balance can be described. A constant temperature during the process can also be assumed [7].

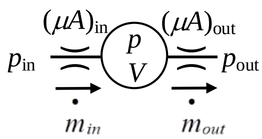


Fig. 2 Schematics to the description of the state of equilibrium of the lumped volume

The flow process is characterized by a high complexity of the occurring phenomena, simplifications have been introduced as follows:

– the air was regarded as a thermodynamically ideal gas (i.e. obeying the Clapeyron law), while being viscous and compressible;

– the flow takes place without internal friction and heat exchange with the surroundings;

– the state of the air is constant in a given volume and depends on time;

– the joints of the individual elements of the tested object are perfectly airtight;

– the air properties were assumed to be uniform both in the local volume and in the entire cross-section of the flow through the local resistance.

Having considered the above assumptions, the differential equation was written showing the pressure change in the lumped element (Fig. 2):

$$\frac{dp}{dt} = \frac{\kappa RT}{V} \cdot \left(\dot{m}_{in} - \dot{m}_{out} \right). \tag{1}$$

For the description of the air mass flow through the local pneumatic resistances, the Saint-Venant-Wantzel relationship in the following generalized form was used:

$$\dot{m}_{in} = \frac{dm_{in}}{dt} = \left(\mu A\right)_{in} \frac{p_{in}}{\sqrt{RT}} \psi_{\max} \psi\left(\sigma\right). \tag{2}$$

The maximum value of the Saint-Venant-Wantzel function for the critical pressure ratio σ* (Eq. 3) (product of the pressure before and past the resistance), which is given by [8, 9]:

$$\sigma^{*} = \left(\frac{2}{\kappa+1} \right)^{\frac{\kappa}{\kappa-1}} = 0.528; \tag{3}$$

$$\psi_{\max} = \psi\left(\sigma^*\right) = \sqrt{\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} = 0.578\,. \tag{4}$$

The two-range function was inconvenient during the numerical calculation, hence the single-range Metlyuk–Avtushko (MA) hyperbolic function [2] (Eq. 5):

$$\psi\left(\sigma\right) = a\frac{1-\sigma}{a-\sigma}\,. \tag{5}$$

A constant parameter value of $a = 1.13$ was assumed, which is typical of the pneumatic elements used in the braking systems of vehicles [2].

Substituting Eq. (2) into Eq. (1), it can be obtained by Eq. 6 (Fig. 2):

$$\frac{dp}{dt} = \frac{\kappa RT}{V}\left(\left(\mu A\right)_{in}\frac{p_{in}}{\sqrt{RT}}0.653\frac{p_{in}-p}{a\,p_{in}-p} - \left(\mu A\right)_{out}\frac{p}{\sqrt{RT}}0.653\frac{p-p_{out}}{a\,p-p_{out}}\right). \tag{6}$$

When developing the mathematical model, the following assumptions were adopted:

– Pressure p_1 at the outlet from the control valve changes along with varying force F_p triggering the displacement of pedal x, because the throughputs $(\mu A)_0$ as well as the $(\mu A)_1$ of the control valve are selected to be sufficiently high.

– It is assumed that the volume of the actuator is constant because its force characteristics (load) is heavily curved in the downward direction.

– The closing element of the valve opens stepwise.

– Coefficient of flow μ does not change during the transient process.

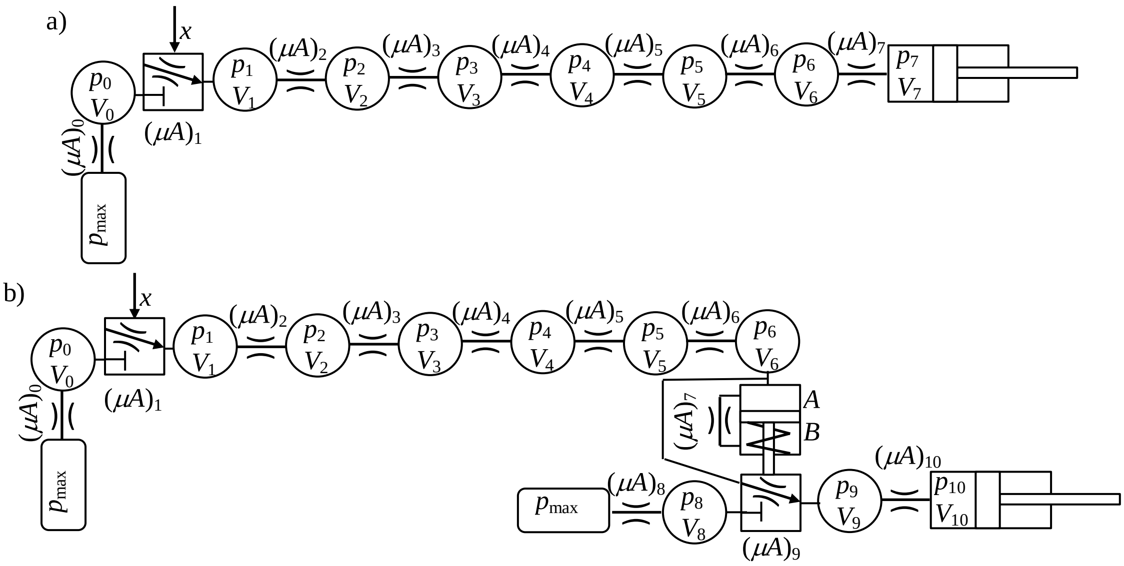


Fig. 3 Schematics of the pneumatic drives used for the modeling (according to Fig. 1a and b)

Utilizing the lumped elements method for pneumatic systems and the Metlyuk–Avtushko flow function [2], the set of equations of the braking process is presented as (Fig. 3, a):

$$\frac{dp_1}{dt} = \left(p_{max} - p_a\right)\frac{t}{t_m} + p_a \quad \text{for} \quad 0 \le t \le t_m\,; \tag{7}$$

$$\frac{dp_2}{dt} = \frac{\kappa RT}{V_2}\left(\left(\mu A\right)_2\frac{p_1}{\sqrt{RT}}0.653\frac{p_1-p_2}{1.13p_1-p_2} - \left(\mu A\right)_3\frac{p_2}{\sqrt{RT}}0.653\frac{p_2-p_3}{1.13p_2-p_3}\right); \tag{8}$$

$$\frac{\mathrm{d}p_3}{\mathrm{d}t} = \frac{\kappa RT}{V_3}\left(\left(\mu A\right)_3\frac{p_2}{\sqrt{RT}}0.653\frac{p_2-p_3}{1.13p_2-p_3} - \left(\mu A\right)_4\frac{p_3}{\sqrt{RT}}0.653\frac{p_3-p_4}{1.13p_3-p_4}\right); \tag{9}$$

$$\frac{dp_4}{dt}=\frac{\kappa RT}{V_4}\left(\left(\mu A\right)_4\frac{p_3}{\sqrt{RT}}0.653\frac{p_3-p_4}{1.13p_3-p_4}-\left(\mu A\right)_5\frac{p_4}{\sqrt{RT}}0.653\frac{p_4-p_5}{1.13p_4-p_5}\right); \tag{10}$$

$$\frac{dp_5}{dt}=\frac{\kappa RT}{V_5}\left(\left(\mu A\right)_5\frac{p_4}{\sqrt{RT}}0.653\frac{p_4-p_5}{1.13p_4-p_5}-\left(\mu A\right)_6\frac{p_5}{\sqrt{RT}}0.653\frac{p_5-p_6}{1.13p_5-p_6}\right); \tag{11}$$

$$\frac{dp_6}{dt}=\frac{\kappa RT}{V_6}\left(\left(\mu A\right)_6\frac{p_5}{\sqrt{RT}}0.653\frac{p_5-p_6}{1.13p_5-p_6}-\left(\mu A\right)_7\frac{p_6}{\sqrt{RT}}0.653\frac{p_6-p_7}{1.13p_6-p_7}\right); \tag{12}$$

$$\frac{dp_7}{dt}=\frac{\kappa RT}{V_7}\left(\left(\mu A\right)_7\frac{p_6}{\sqrt{RT}}0.653\frac{p_6-p_7}{1.13p_6-p_7}\right), \tag{13}$$

where p_a i $p_{\max}$ is the atmospheric and maximum pressure (absolute); t_m is time of pedal force change (from zero to maximum); $p_1 \ldots p_6$ are the absolute air pressures in lumped elements; p_7 is absolute air pressures in piston rod; V_1 is the total volume of the internal chamber of the control valve and half of the pipe section; $V_2 \ldots V_6$ are the internal volumes of each section of the pipe; V_7 is the total volume of the piston rod chamber and the middle of the pipe section; μ is the discharge coefficient; A is the flow cross-section area; κ is the adiabatic exponent; R is the gas constant; T is the absolute temperature of the air; $(\mu A)_i$ is the throughputs (conductance).

The pressure in all the lumped elements of the calculation circuit changes from $p_a = 1\ 10^5$ Pa to $p_{\max} = 8\ 10^5$ Pa. The increment of force on the pedal is linear. Pressure p_0 and p_8 in the control and differential chambers (Fig. 3) supplied to the receiver is constant and is at its maximum $p_{\max}$, which is admissible at relatively high values of $(\mu\mathrm{A})_0$ and $(m\mathrm{A})_8$. Coefficient of flow μ of the selected portion of the line is determined based on the relation:

$$\mu=\frac{\mu_j}{\sqrt{j}}, \tag{14}$$

where μ_j is the discharge coefficient of a one meter long pipe section; j is the number of one meter pipe lengths in the design drive.

The transient process in the drive according to Fig. 3b is described with a set of equations: Eq. (7)-(13), and:

$$\frac{dp_9}{dt}=\frac{\kappa RT}{V_9}\left(\left(\mu A\right)_9\frac{p_8}{\sqrt{RT}}0.653\frac{p_8-p_9}{1.13p_8-p_9}-\left(\mu A\right)_{10}\frac{p_9}{\sqrt{RT}}0.653\frac{p_9-p_{10}}{1.13p_9-p_{10}}\right); \tag{15}$$

$$\frac{dp_{10}}{dt}=\frac{\kappa RT}{V_{10}}\left(\left(\mu A\right)_{10}\frac{p_9}{\sqrt{RT}}0.653\frac{p_9-p_{10}}{1.13p_9-p_{10}}\right), \tag{16}$$

where $\left(\mu A\right)_9=\left(\mu A\right)_{9\,max}$ and $p_8 = p_{max}$ for $p_6 S\eta \geq p_7 S + F_{sp}$.

$$\left(\mu A\right)_9=\left(\mu A\right)_{9\,max}^{`} \quad \text{and} \quad p_8 = p_6 \quad \text{for} \quad p_6 S < p_7\cdot S + F_{sp}, \tag{17}$$

and S is the cross-section of the differential valve piston; F_{sp} is the spring force in the valve; μ is the efficiency factor of the valve; p_6 and p_7 are pressure in the chambers A and B of the valve; $(\mu A)_9$ is throughput of the valve.

Due to their size, the input data and the boundary conditions necessary to initiate the calculations have been omitted in the work. As of the moment of initiation, $p_0 = p_8 = p_{\max} = 8\ 10^5$ Pa and the outstanding $p_i = p_a = 1\ 10^5$ Pa. Upon calculations with the substitution of actual values of the geometrical and pressure supply parameters in the above equations and following the experimental research, the following has been obtained:

– The application of a differential valve in long lines (12...18 m) results in a significant increase in the drive responsiveness;

– The efficiency (displacement $t_2 - t_1$ in Fig. 1) of the differential valve depends on the drive parameters as a whole, the parameters of the valve itself (particularly its throughput $(\mu A)_7$) and the volumes of chambers A and B (Fig. 3, b);

– The developed method of dynamic calculation of pneumatic drives is convenient and sufficiently accurate – the differences between the calculated values and the ones obtained in the experiment do not exceed 7%.

The example results of the calculations made in Matlab-Simulink for two systems with a pneumatic piton rod (see Fig. 3) have been shown in Fig. 4.

Comparing the two systems (Fig. 5) at a different force increment on the pedal, the correctness of operation of the differential valve was confirmed. When the force grows in the time of 1 s, the differential valve is inactive and the system behaves normally as if the valve was not installed.

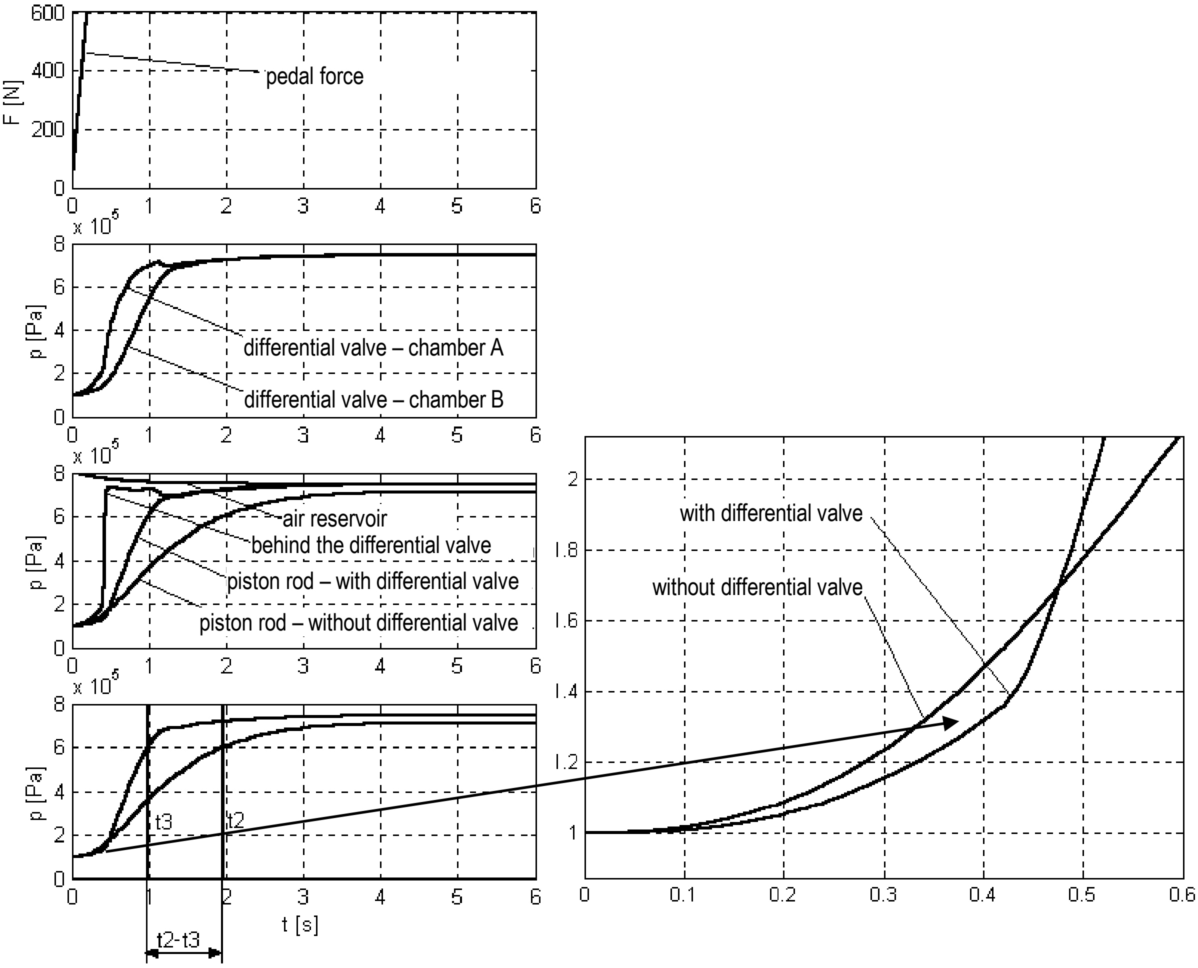


Fig. 4 Comparison of the pressure curves at selected points of the two systems for the force increment on the pedal of 0.2 s

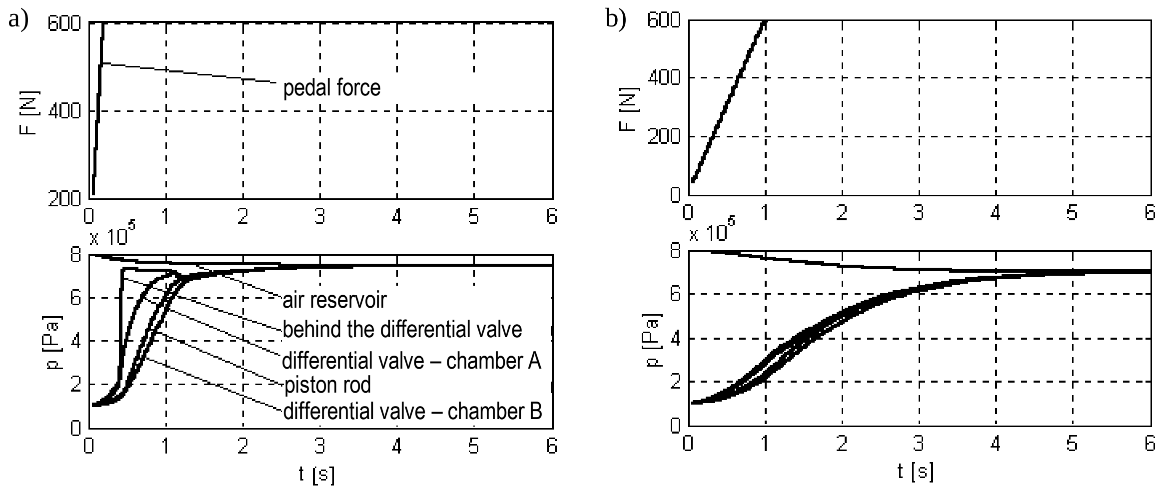


Fig. 5 Comparison of the pressure curves at selected points of the two systems for the force increment on the pedal 0.2 s (a) and 1 s (b)

4. Conclusions

The application of a differential valve in pneumatic drives of brake systems in road trains significantly reduces the time of the transient process. As a result, the responsiveness of the brake system increases, particularly in the case of sudden brakes. This improves the traffic safety. The analysis of the results of the calculations confirms that appropriate selection of parameters of both the pneumatic drive as a whole and the differential valve may lead to the desired effect. A prototype of the proposed valve was also developed that confirmed the correctness of the adopted assumptions and analyses.

Acknowledgment

The research has been carried out within work no. S/WM/1/2018 realized at Bialystok University of Technology and financed from the funding allocated for science by the Ministry of Science and Higher Education – Poland.

References

1. **Waluś, K.J.** 2017. Driver's Strategy and Braking Distance in Winter. Transport Means 2017: Proceedings of the 21st International Scientific Conference 2: 505-509.
2. **Metlyuk, N.F.; Avtushko, V.P.** 1980. Dinamika pnevmaticheskih i gidravlicheskih privodov avtomobilej. Mashinostroenie, 231 p. (in Russian).
3. **Kamiński, Z.; Kulikowski, K.** 2015. Determination of the functional and service characteristics of the pneumatic system of an agricultural tractor with mechanical brakes using simulation methods, Eksploatacja i Niezawodnosc – maintenance and Reliability 17 (3): 355-364. http://dx.doi.org/10.17531/ein.2015.3.5.
4. **ECE Regulation No. 13**. Uniform provisions concerning the approval of vehicles of categories M, N and O with regard to braking. UN Economic Commission for Europe, Geneva, Switzerland, 2001.
5. **Kamiński, Z.** 2017. A simplified lumped parameter model for pneumatic tubes, Mathematical and Computer Modelling of Dynamical Systems 23(5): 523-535. https://doi.org/10.1080/13873954.2017.1280512.
6. **Kamiński, Z.** 2012. Mathematical modelling of the pneumatic relay emergency valve for dual–line agricultural trailer braking systems, Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering 226(5): 603-612. http://dx.doi.org/10.1177/0954407011423133.
7. **Iwaszko, J.** 1988. Wymiana ciepła podczas opróżniania zbiornika, Zeszyty Naukowe Politechniki Łódzkiej, Cieplne Maszyny Przepływowe 520(93): 95-113 (in Polish).
8. **Grymek. S.; Kiczkowiak, T.** 2005. Conversion of the sonic conductance C and the critical pressure ratio b into the airflow coefficient μ, Journal of Mechanical Science and Technology 19(9): 1706-1710. https://doi.org/10.1007/BF02984182
9. **Beater, P.** 2007. Pneumatic Drives. System Design, Modeling and Control, Berlin, Heidelberg, Springer-Verlag, 324 p. http://dx.doi.org/10.1007/978-3-540-69471-7.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Urban Real Driving Analysis with and without Coordinated Traffic Lights Control

J. Kreicbergs[1], M. Gailis[2], A. Grislis[3]

[1]*Riga Technical University, 1 Kalku Str., LV1658, Riga, Latvia, E-mail: Juris.Kreicbergs@rtu.lv*
[2]*Riga Technical University, 1 Kalku Str., LV1658, Riga, Latvia, E-mail: Maris.Gailis@rtu.lv*
[3]*Riga Technical University, 1 Kalku Str., LV1658, Riga, Latvia, E-mail: Aivis.Grislis@rtu.lv*

Abstract

The significance of real driving fuel consumption and emissions compared to laboratory tests has grown both because of emissions testing faults publicity and inclusion of real world emissions measurements in the new worldwide harmonised light-duty vehicles test procedures (WLTP). Urban driving represents approximately one third of distance in the WLTP real driving test. City driving conditions differ essentially by city environments, weather and traffic conditions. To analyse the urban driving variations a 25 km route was selected in Riga city comprising major city transport arteries in both directions. The route contains 15 km of road sections with coordinated traffic lights control. The city street configuration allows formation of green wave just in one direction so the other direction formats an organized traffic restraint. Street sections with three different traffic control conditions have been compared. The sections with coordinated traffic lights control in the green wave direction show the biggest around the clock variations which may be essential to note when real driving emissions are measured. The sections in the controlled traffic restraint direction may be useful for real driving tests where repetitive driving conditions are preferred. Up to five times higher fuel consumption has been measured in peak traffic hours compared to night driving. The paper analyses suitability of the route for urban driving tests by analysing average speeds and fuel consumption during 24 hours of urban traffic changes. The paper blends in a more extensive research on energy consumption in urban driving.

KEY WORDS: *urban driving, fuel consumption, coordinated traffic control, green wave*

1. Introduction

Vehicle emissions and fuel consumption are of constant public and automotive stakeholders concern which peaked after VW diesel emissions scandal publicity. This highlighted findings of previous studies and facilitated research activities comparing the formal test methods with real life driving. Researchers and public organizations in Europe have emphasized the growing difference between the NEDC test procedure and actual fuel consumption and CO_2 emission data [1-3]. A new test procedure WLTP and corresponding driving cycle that is expected to be essentially closer to real world driving has been developed as a part of World Forum for Harmonization of Vehicle Regulations activities and already is in force having an introduction transition period up till 2020. Research and simulation for appropriateness of the new procedure has already started and researchers are trying to find out what improvement can be expected by WLTP introduction [4]. The essential difference of the WLTP procedure is having measurements in real world driving.

Real driving data as contrary to test bench analysis is much harder to be cheated and may be more trusted by car users. Unfortunately it has many disadvantages like being dependent on road environment (city, rural or motorways, plain or with steep grades, congested or deserted), vehicle maintenance, weather conditions, driving styles and driver's intentions. The partial solution to this problem is increasing the car fleet tested but it does not give precise characteristics for every car in use, therefore are attempts of local research activities to obtain seemingly more relevant and definitely more understandable data.

There have been several tries in Latvia to create localized test procedures. Already for years researchers use driving cycle developed for Jelgava city [5]. Some driving cycles are developed even for more narrow usage [6]. Still to have knowledge about the correspondence of the local conditions to the new test technologies, it was decided to evaluate the suitability of using for tests the driving pattern enforced by the coordinated traffic lights control in Riga city because it includes the advantages of real life driving and contains elements of test bench cycles where the speed changes are strongly influenced by traffic lights control plan. The research was also encouraged by affordable GPS technologies and suitability of OBD data for fuel consumption measurements, as proved by other researchers [7].

2. Materials and Methods

There is a very limited choice of road sections with coordinated traffic light control in Riga city. Three main streets leading in and out of the city centre towards outer city on one side and towards two bridges on the other side have non-elastic coordinated traffic lights control with round the clock constant lights timing scheme. The advantage of

selecting these streets for the tests is that the streets enclose the active city centre outside the old town where the traffic is highly restricted. The test route was planned to include all three streets in both directions in full length of the coordinated traffic sections. The traffic light plans have been acquired from traffic planning group of Riga City council.

Several cars have been repeatedly driven along the test route, but most of the tests were done with Opel Zafira 2004 with a 1.6i-16V petrol engine. For the results to be more comparable, only results from this car are used in this paper. To ensure a controllable driving pattern, all tests were done by the first author of the current paper. Having experience with eco-driving and other driving styles for these tests a generous driving style was used – economical driving but without any disturbance to the traffic flow by extensive gliding or slow driving, avoiding speeding but without an audible signal or other feedback for precise maintaining of the permissible speed. No stop – start system was used to allow later analysis of the system usability for the test route. The paper analyses 41 times driving along the test route planned at various time of day with a total test length around 1000 km and 45 hours.

Speed, fuel consumption and engine speed have been recorded by OBD logger Auterra DashDyno SPD. GPS time, vehicle speed and GPS position were recorded by GPS logger RaceLogic DriftBox having a 10 Hz recording frequency.

The total test route exported to Google Earth is shown on Fig. 1. The street sections with coordinated traffic light control are shown in white with a thicker line. The street plan and existing speed limits do not allow planning of green wave traffic in both directions, therefore the city planners have decided to make the green waves in the direction out of the city (up and to the right on Fig. 1). The sections without coordinated control are shown with a thinner line.

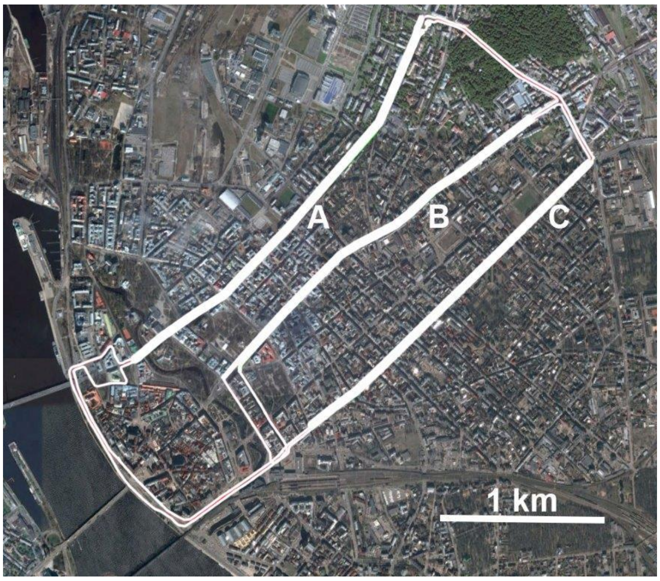


Fig. 1 Test route in Riga city: A – Valdemāra, B – Brīvības, C - Čaka

The lengths of the route, street names with symbols used on Fig. 1 and green wave directions are shown in Table 1, where GW – in the direction of green wave, AGW – against the direction of green wave.

Table 1

Test route sections with coordinated traffic lights

Street	Street on Fig. 1	Control type	Length, km
Brīvības	B	AGW	2.47
Čaka	C	GW	2.35
Kr. Valdemāra	A	AGW	2.76
Brīvības	B	GW	2.54
Čaka	A	AGW	2.35
Kr. Valdemāra	C	GW	2.69

The driving starts at the northern corner of the route, going towards Brīvības Street, continuing the coordinated sections in the sequence shown in Table 1, having shorter connections on Raiņa and Merķeļa Streets, and more extensive connections on Pērnavas Street and the towards and along the Daugava river embankment 11. Novembra krastmala. The total lengths of coordinated sections is 15.16 km, non-coordinated sections 9.48 km, counting 24.64 km for the entire route. Since driving takes slightly different trajectories, average measured distances are given. Some streets change their names along the length covered, just one name for any street is mentioned.

Date from the loggers are exported using OEM software. Any further calculations are done using MS Excel with extensive use of Microsoft Visual Basic for Applications. The first stage of data processing is synchronising OBD data

with GPS data, including visual confirmation of matching speed changes recorded by both devices.

The GPS coordinates for street section limits and intersections are taken from Google maps and compared with GPS coordinates given by OEM software. Section start, finish and every street junction position are added to the data table by minimizing the calculated distance between each recorded GPS coordinate and coordinates of section limits using the flat Earth model:

$$D = R \cdot \sqrt{\left(LATr - LATp\right)^2 + cos\left(\frac{LATr + LATp}{2}\right) \cdot \left(LONr - LONp\right)^2}\ , \tag{1}$$

where D – distance between the measured point and the section limit, m; R – Earth radius, m; $LATr$ – GPS coordinate latitude on the route, rad; $LATp$ – GPS coordinate latitude for the section limit, rad; $LONr$ – GPS coordinate longitude on the route, rad; $LONp$ – GPS coordinate longitude for the section limit, rad.

To check the traffic lights green wave operation, the time difference between the recorded GPS time and certain time at the start of the tests was calculated, divided by the traffic lights cycle length obtaining the reminder corresponding to the time from the start of given traffic light cycle.

3. Results and Discussion

The operation of traffic lights one-way green wave is shown on Fig. 2 where the time from the start of the traffic lights cycle is plotted against the distance. The grey lines are in the direction of green wave, the black lines are in the opposite direction against the green wave. Each line corresponds to a single driving along the test route. All three streets have similar traffic lights control therefore the plot is given here for Valdemāra Street only. The distance is shown away from the city centre. The wide spread of green lines along the time corridor in the green wave direction shows good operation of the green wave. The black lines clearly form four places where the traffic is stopped on most occasions.

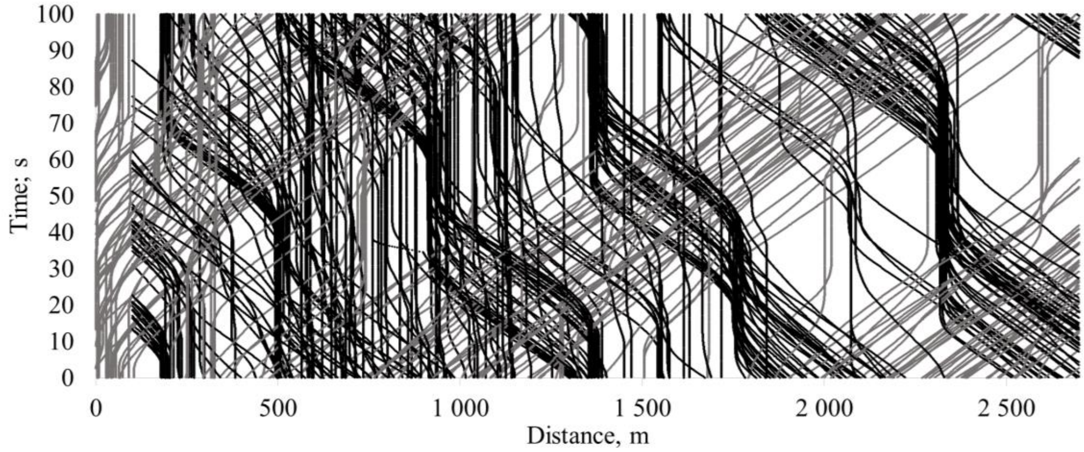


Fig. 2 One way green wave on Valdemāra Street

The functioning of green wave can also be evaluated by comparing average speeds on coordinated street sections. The plot on Fig. 3 showing average speeds at different hours of day for every tested street section both in the direction of green wave and opposite direction, complimented by the average speed for the remaining route sections without coordinated lights control.

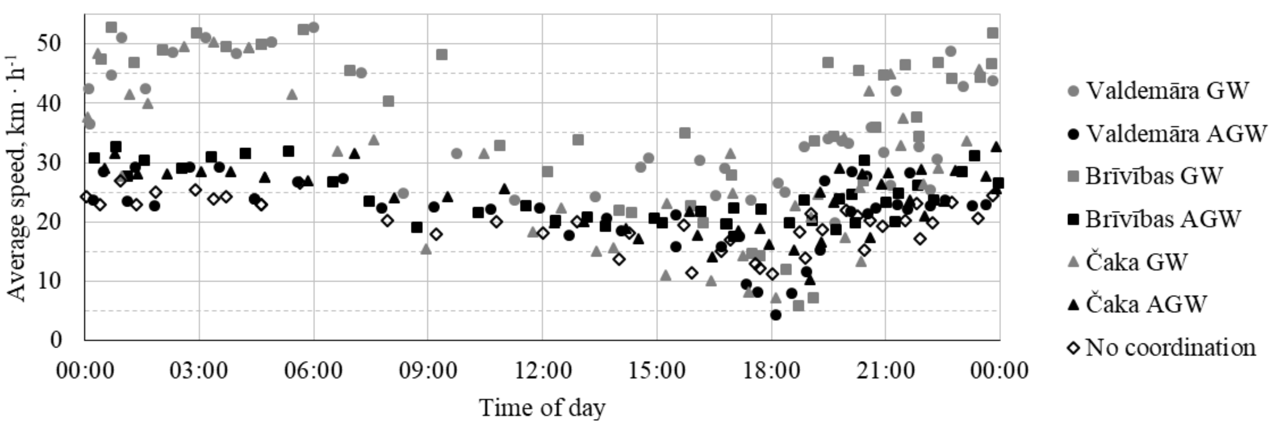


Fig. 3 Change of average speed during day hours on test sections

It can be seen that the street sections with green wave have essentially bigger amplitude in average speed changes during the day and higher spread of speed values during most of the day than on sections against green wave and uncoordinated sections. As expected the average speed values for sections in the direction of green wave are higher while at the afternoon peak hour there is no essential difference between both type of coordinated sections and uncoordinated sections.

The plot does not represent the whole range of possible speeds on given road sections since the tests were not performed during street repair works, there was no occasion of traffic accidents during the tests and the test plan did not include trying to assess the most congested days. All tests were performed on weekdays, excluding weekends and public holidays. It also can be noted that for certain occasions the average speed on the all section is less important than just for the part of the section. The minimum speed recorded was AGW on Valdemāra Street where the exit from the section is leading towards the busiest bridge and therefore the speed on the second part of the section is much more important than the average speed for the whole section.

This paper is a part of broader tests devoted to fuel and energy consumption therefore here the measured fuel consumption values on the tested road sections is displayed.

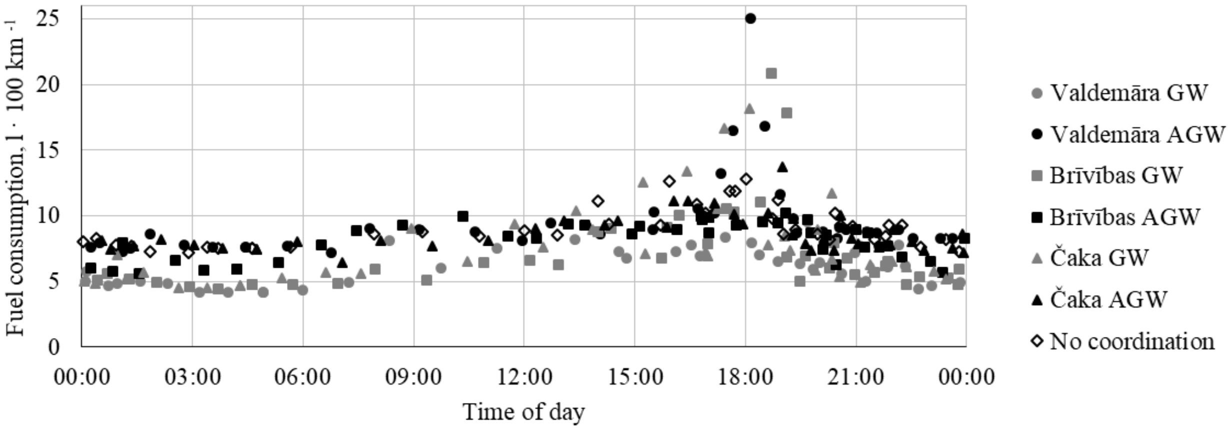


Fig. 4 Change of fuel consumption during day hours on test sections

The fuel consumption measurements on Fig. 4 show just one remarkable peak during the evening rush hour around 6 pm but no essential growth of fuel consumption was observed during the morning rush hours. This could be explained because most of the test sections are located after the bottlenecks on bridges leading the traffic towards the city centre while the same bottlenecks form when the traffic leaves and then the congestions are on the street sections under the investigation.

Having the fuel consumption changing more than five times, Fig. 4 does not always allow to distinguish between the measurements therefore a zoomed-in Fig. 5 is added.

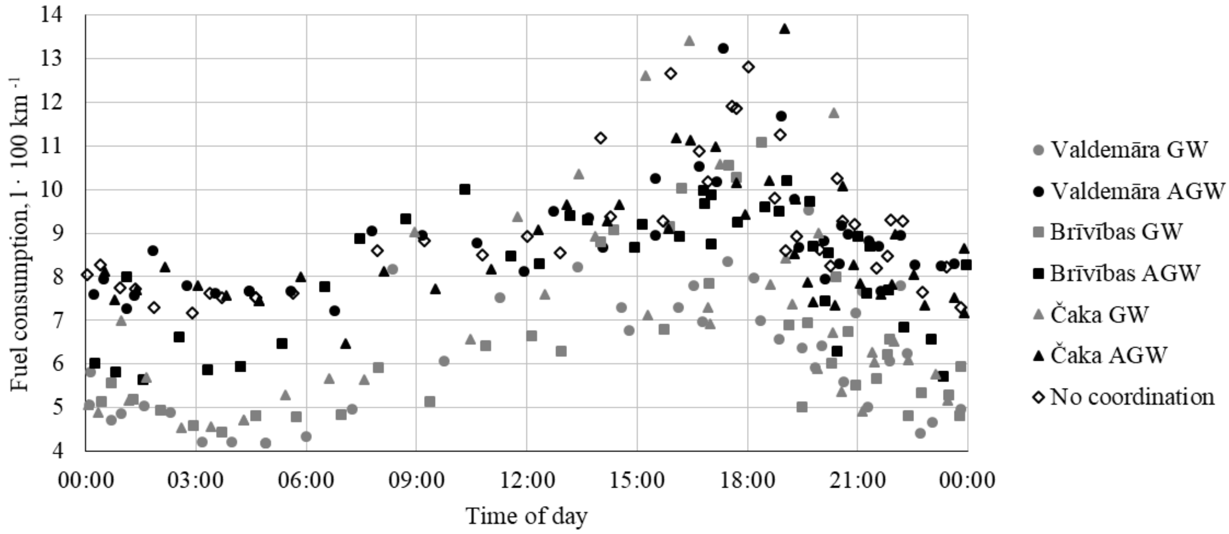


Fig. 5 Zoomed-in fuel consumption during day hours on test sections

Analysing the fuel consumption on the sections with green wave, the lowest values and the less changing performance is seen on Valdemāra Street. This may be explained by the longer total traffic lights cycle of 100 s compared to 80 s on other streets allowing better formation of the green wave and by the fact that there are no bottlenecks at the end of the section. It also confirms that keeping the congestion on the bridge in the morning hours where the extra air

pollution is better dissipated than in the city centre and the facilitating leaving the centre is rather successful. Green wave on Brīvības street is quite good during most of the day but does not work well when the traffic is leaving the city after the working hours, most probably due to the narrow bridge across railway at the continuation of the street. The green wave on Čaka Street gives good results during the night but having wide results distribution during and after the working day, possibly because of the narrow street where any single disturbance on the street changes the traffic flow.

The direction against the green wave on Valdemāra Street and Čaka Street gives the highest fuel consumption values and quite similar pattern during the day, with some higher peaks for Valdemāra Street where the bridge crossing problems are more critical. Brīvības Street shows more steady performance against the green wave since not having that good access to the bridges as other streets and due to the noticeable red traffics light wave closer to the city entre does not attract as many traffic as the other streets under investigation.

The objective of the current research was not to fully examine the street grid for city planning reasons but to assess the analysis chances with affordable GPS and OBD technologies. The other point of interest was to look at the results gained by rather simple inelastic traffic lights coordination's schemes while cities introduce more advanced systems.

The most expected result was assessment of repeatable urban real driving tests on different street sections. Some other fuel consumption tests on the selected route have already be done. To obtain repeatable test results in off test bench investigations the measurements have been carried out during the night hours where the steady speed driving with low engine loads on green wave sections alternate with stop and go movement against the green wave. When planning urban driving tests expecting repeatable results during daytime it would be advisable to limit the usage of sections with green wave traffic lights control because they are more subject to changes due to various factors.

4. Conclusions

GPS and OBD technologies allow to perform urban real driving tests examining street sections along the planned route.

To obtain repeatable off test bench driving tests in stop and go traffic, urban routes with extensive inclusion of non-elastic control coordinated traffic lights sections may give steady results.

OBD and GPS measurements may facilitate evaluation of city traffic planning decisions.

The biggest challenge of the current traffic control system in Riga city centre on the streets investigated is Valdemāra Street in the direction towards the bridge.

References

1. **Duarte, G.O.; Gonçalves, G.A.; Baptista, P.C. etc.** 2015. Establishing bonds between vehicle certification data and real-world vehicle fuel consumption – A Vehicle Specific Power approach. Energy Conversion and Management 92: 251-265.
2. **Tietge, U.; Mock, P.; Franco, V. etc**. 2017. From laboratory to road: Modeling the divergence between official and real-world fuel consumption and CO2 emission values in the German passenger car market for the years 2001–2014. Energy Policy 103: 212-222.
3. **Mock, P.; German, J.; Bandivadekar, A. etc**. 2013. From laboratory to road. A comparison of official and 'real-world' fuel consumption and CO2 values for cars in Europe and the United States. White Paper. Washington: International Council of Clean Transportation, May 2013. 77 p.
4. **Fontaras, G.; Ciuffo, B.; Zacharov, N. etc**. 2017. The difference between reported and real-world CO2 emissions: How much improvement can be expected by WLTP introduction? Transportation Research Procedia, Vol. 25: 3933-3943.
5. **Dukulis, I.; Pirs, V.** 2009. Development of Driving Cycles for Dynamometer Control Software Corresponding to Peculiarities of Latvia. Agricultural Engineering. Research for Rural Development. 95-102.
6. **Berjoza, D.; Pirs, V.; Dukulis, I. etc**. 2016. Development and analysis of a driving cycle to identify the effectiveness of the vacuum brake booster. Agronomy Research 14(3): 672-682.
7. **Lee, M.G., Park, Y.K., Jung, K.K. etc**. 2011. Estimation of Fuel Consumption using In-Vehicle Parameters. International Journal of u- and e- Service, Science and Technology 4: 37-46.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Risk Analysis of Accidents in Poland Based on ARIMA Model

A. Borucka

Military University of Technology, Urbanowicza 2 Str, 01-476, Warsaw, Poland, E-mail: anna.borucka@wat.edu.pl

Abstract

Road safety statistics show that this is still a very serious problem. Many factors affect the security level. Some of them are difficult for predicting and independent of the man e.g. weather conditions, time of the day or year. Other – as the type and number of available transport routes, condition and quality of elements of the infrastructure, for the maintenance of which people are responsible, are difficult to change and require huge expenses. However, undoubtedly road users are the weak point of this system. Most often these are their mindlessness and bravado, as well as lack of concentration and non-observance of traffic regulations or the ride after drinking alcohol are the causes of accidents. Therefore, the most important is to constantly raise their awareness, to which contributes this article in which the time series ARIMA model was used to analyze the risk of accidents on Polish roads. The presented model allows for a mathematical description of the phenomenon, as well as prediction of the number of accidents in the future. It can be used not only to assess potential risks, but also as a part of education and information campaigns.
KEY WORDS: *ARIMA model, road safety, risk of road traffic accidents*

1. Introduction

There are many causes of road accidents. These include issues related to the condition of transport infrastructure, technical efficiency of vehicles and predisposition of road users. This is compounded by issues that are difficult for man to shape, such as weather conditions, time of day or year. Their detailed study requires gathering a lot of data, often difficult to analyze not only because of their quantity requiring specialized software and computers with high computational capabilities, but also because of mutual permeation and interdependence that often makes it impossible to analyze the impact of a specific factor. Therefore, this article proposes the use of autoregressive mathematical model, built on the basis of deterministic concept of the existence of relation between values of time series at a given moment and its values in previous moments. One of models, based on the correlation phenomenon between values of analyzed series at moments distant from each other by a certain period of time, is ARMA [1-3]. In order to achieve greater efficiency, two processes were combined in it: moving average MA in which the values of dependent variable are explained by delayed values of the stationary random element and autoregression AR using the relation between values of forecasted variable and its values delayed in time. Such models are used for stationary series or for series, which after differentiation procedure, were if necessary reduced to a stationary form. Then they are called ARIMA [1-3].

2. Research Methodology

The guarantee of obtaining satisfactory model is the correctness of data used for its construction. Therefore, firstly it is necessary to check its quality and homogeneity, as well as and to carry out analysis in terms of future estimation [1, 2, 3]. Information on the number of accidents that took place in Poland in 2013-2017 was used for this research [5].

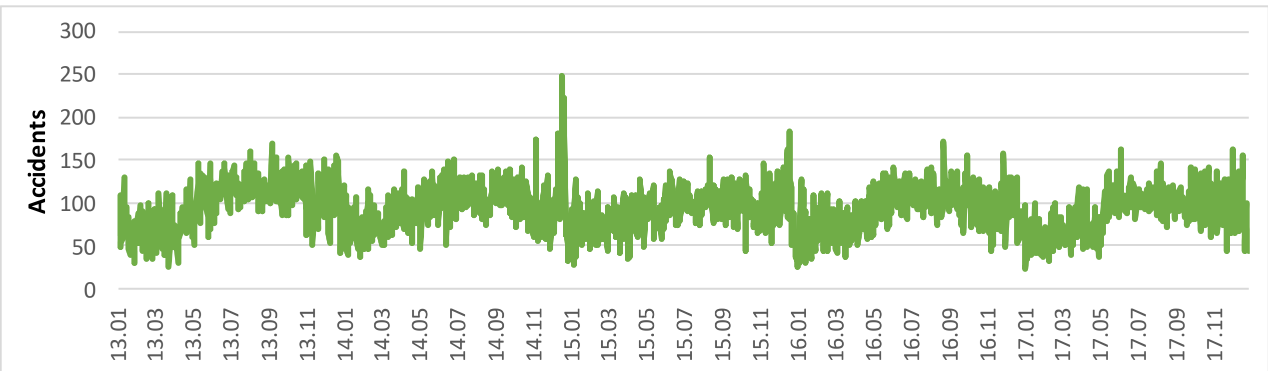


Fig. 1 Number of accidents in Poland in 2013-2017

The substantive correctness of data is ensured by a history diagram, descriptive statistics (Table 1) and distribution histogram of analyzed variable.

Table 1

Basic descriptive statistics

Variable	Basic descriptive statistics						
	Count (N)	Mean	Median	Minimum	Maximum	Standard deviation	Coefficient of variation
Accidents	1826	93,21	94	22	248	25.75	27.63

The line chart (Fig. 1) clearly shows the existence of untypical observations. Since they can strongly affect the model estimation results, they need to be carefully studied. High indications also increase the value of the coefficient of variation, which is 27%, which may difficult to obtain reliable forecasts. The position of median in relation to the average is satisfactory, and the values are very close to each other. In order to select the right filter for outlier observations, a detailed inspection of the empirical distribution and characteristics of observations are necessary.

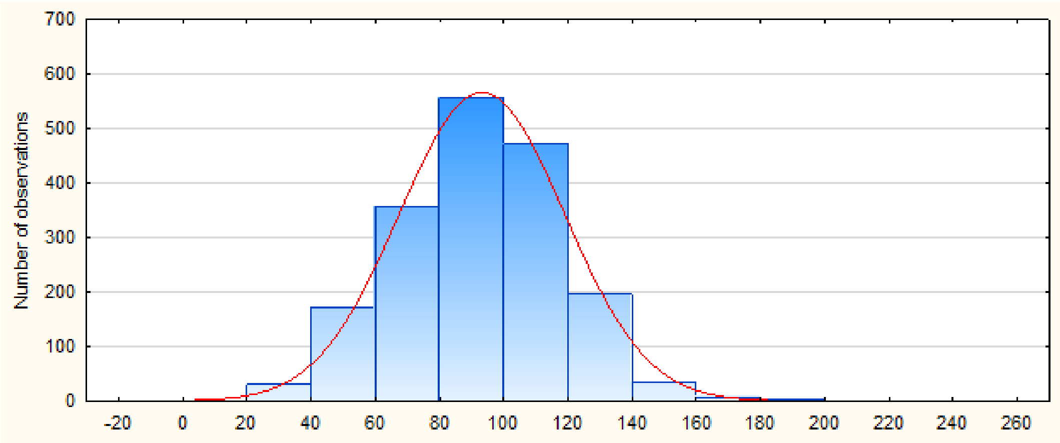


Fig. 2 Histogram of studied variable

The accidents, which significantly differed from the average value, were related to Christmas periods in which increased mobility took place, resulting from trips to family and friends. Due to the fact that such observations differed from the natural rhythm of road traffic, it was decided to exclude them from the analysis. The variable distribution, shown in Fig. 2, indicates that it is close to normal, and therefore untypical observations according to 3 sigma range have been removed, and the resulting missing observations have been replaced with a median [3, 4]. The variable prepared in this way was subjected to further study. The use of ARIMA model forces the process to be stationary. In order to check this assumption, correlograms were determined, which turned out to be significantly negative and slowly decreased with each delay, which means a non-stationary process. That is why the differentiation operation was carried out, thus reducing the series to stationary. In order to stabilize the variance, a logarithm was conducted. After carried out transformations, homogeneous data were obtained, ready for estimation.

3. Research Results

The most difficult stage of building the ARIMA model is identification, which consists in finding appropriate values of function parameters. As the analyzed process is characterized by seasonality, as shown in Figure 1, it must be taken into account. SARIMA (Seasonal ARIMA) is a model that enables the seasonal element to be included [3]. Then, in addition to parameters *p, q* that describe the autoregression and moving average process, and *d* that informs about the series integration level, i.e. the number of performed differentiation operations, it is necessary to define three parameters taking into account the seasonal component, i.e. *P* –seasonal delays row of AR type, *Q* – seasonal delays row of MA type, *D* – seasonal differentiation parameter, *m* – length of seasonality cycle (e.g. 4 for quarterly data, 12 for monthly data, 5 or 7 for daily data, etc.) – Fig. 3.

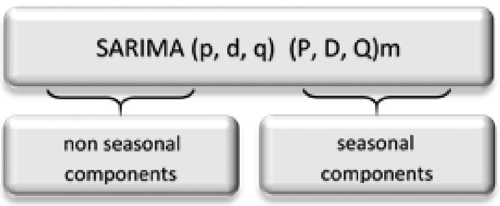


Fig. 3 Construction of SARIMA model

Correlograms (Fig. 4 and Fig. 5) are helpful in selection of the right parameters for ARIMA model [1-4]. Since

the autocorrelation functions ACF and partial autocorrelation functions PACF decrease relatively quickly, but there are many coefficients significantly different from zero, it indicates the existence of both the moving average and auto-regression process. In addition, regular changes in these functions, especially for a delay of 7 and its multiplication, confirm the seasonality.

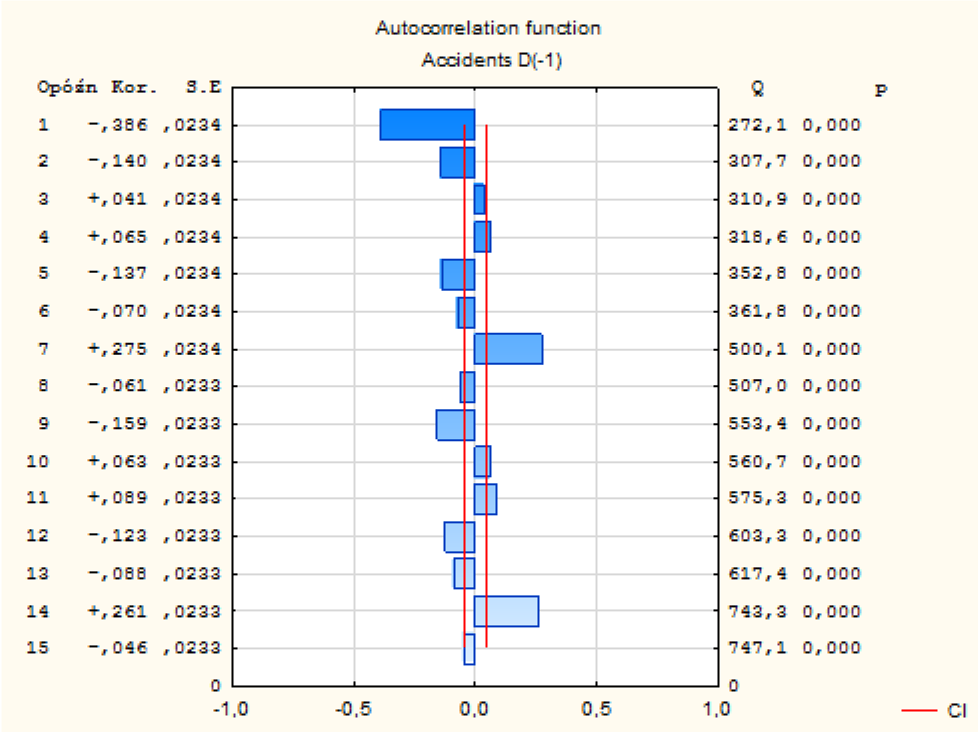


Fig. 4 Autocorrelation function of delayed variable accidents

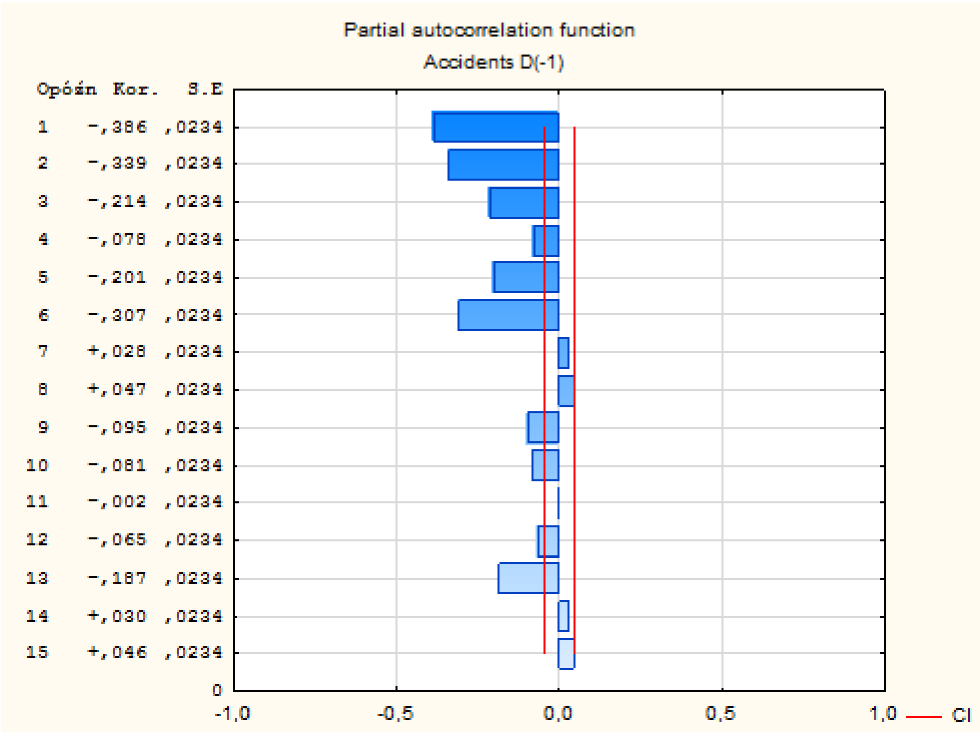


Fig. 5 Partial autocorrelation function of delayed variable accidents

In practice, the maximum possible number of delays due to corelograms is most often chosen, and the model is estimated for all possible combinations of parameters, based primarily on their statistical significance. The final selection is made by comparing the values of information criteria with those of the mean square error. For analyzed data the best model turned out to be SARIMA (6.1.2)(2.1.1) model with seasonal delay $D = 7$, which parameters are presented in Table 2.

Table 2

Estimation results of SARIMA (6,1,2)(2,1,1) model

Parameters	SARIMA (6,1,2)(2,1,1)				
	Parameters value	Standard error	p-value	Lower limit of 95% CI	Upper limit of 95% CI
p(1)	0.862176	0.047412	0.000000	0.769188	0.955165
p(2)	-0.654984	0.061086	0.000000	-0.774792	-0.535177
p(3)	0.648553	0.051542	0.000000	0.547466	0.749641
p(4)	-0.589539	0.051017	0.000000	-0.689597	-0.489480
p(5)	0.538299	0.046059	0.000000	0.447964	0.628633
p(6)	-0.458548	0.041367	0.000000	-0.539679	-0.377417
q(1)	0.589309	0.051249	0.000000	0.488795	0.689823
q(2)	0.312470	0.052168	0.000000	0.210153	0.414786
Ps(1)	0.449958	0.038957	0.000000	0.373553	0.526364
Ps(2)	-0.182405	0.035914	0.000000	-0.252843	-0.111967
Qs(1)	0.909081	0.015887	0.000000	0.877923	0.940239

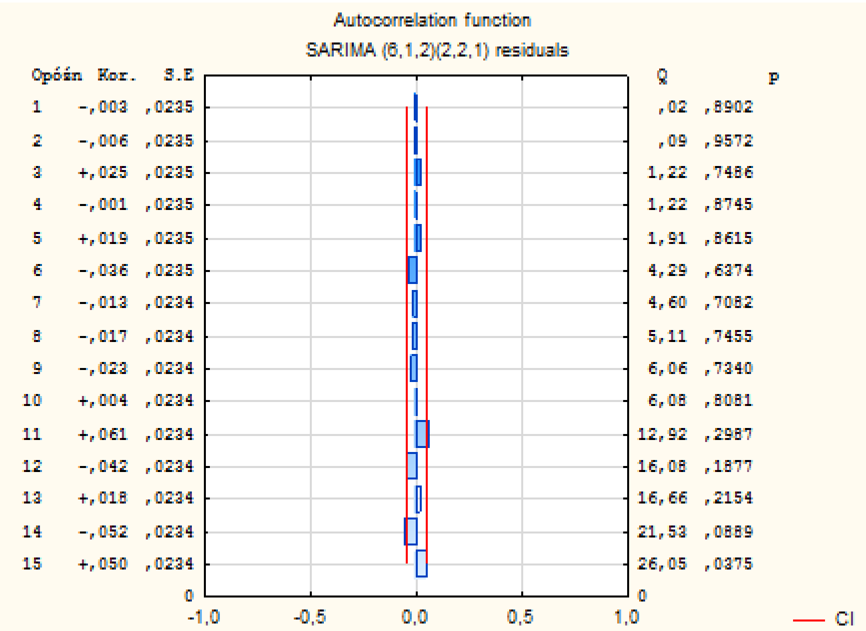


Fig. 6 Partial autocorrelation function of residuals

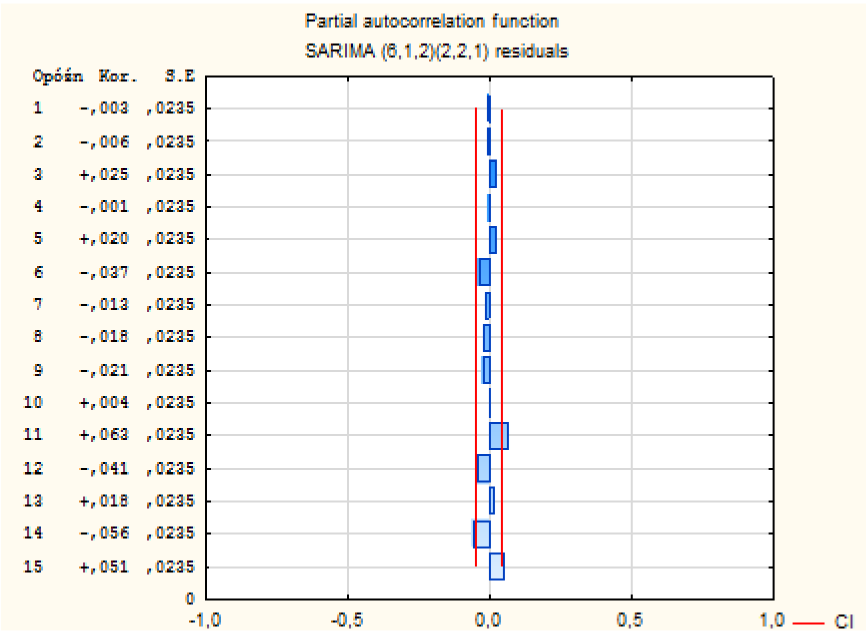


Fig. 7 Partial autocorrelation function of residuals

The next step is diagnostics, which is based on the analysis of residuals properties. In a properly constructed model, they are a white noise process, which means that there are no significant ACF or PACF function values, as shown in diagrams below (Fig. 6 and Fig. 7). Therefore, the model can be used for forecasting purposes.

The effectiveness of model in forecasting has been verified using observations from the beginning of 2018. However, this is a period which is characterized by some deviation from the rest of the year, due to appearing public holidays and holiday, which people often extend by taking additional special days of leave. Therefore, the forecasting error on 1 January (New Year) is as much as 86%, as it is a day devoted mainly to rest, less frequently to travel (Table 3).

Table 3

Comparison of forecasts and empirical test values

Date	Forecast SARIMA model	Empirical data	Mean standard error Ψ [%] SARIMA (6,1,2)(2,1,1)
2018-01-01	83.7013	45	**-86.00**
2018-01-02	77.1338	84	**8.17**
2018-01-03	97.5485	106	**7.97**
2018-01-04	91.8825	66	**-39.22**
2018-01-05	109.2366	108	**-1.15**
2018-01-06	73.1487	43	**-70.11**
2018-01-07	69.3242	49	**-41.48**
2018-01-08	89.0267	74	**-20.31**
2018-01-09	88.2127	76	**-16.07**
2018-01-10	90.9713	77	**-18.14**
2018-01-11	95.0478	90	**-5.61**
2018-01-12	102.0554	73	**-39.80**
2018-01-13	77.0736	56	**-37.63**

The average relative forecast error for the test period is 30%, and excluding 1 January 2018 – 25%, which can be considered as a satisfactory result.

4. Conclusions

Factors that have a determining influence on road safety are elements of human – road – vehicle system. This system is also subject to many external influences, such as weather conditions, time of day or season. However, the main cause of road accidents is always a man, his indecision and bravado. Among the reasons resulting from a fault of the vehicle driver, the most frequently recorded are lack of inappropriate speed to existing traffic conditions, failure to observe the priority of driving, improper behavior towards the pedestrian or overtaking. Therefore, any action to increase prudence and caution on the road is desirable. Awareness-raising is also conducive by mathematical models, which show how the number of accidents will develop in the future while maintaining the existing relations. Such analyses may be very complex and involve many factors affecting the safety, but they may also be based on time relations in a series, as in this Article. The presented model in a satisfactory way met the predictions of the number of road accidents, becoming a good tool to forecast them. Moreover, by showing the phenomenon scale, it also becomes a part of information, education and prevention functions, which is also its undoubted asset.

References

1. **Bielińska, E.** 2007. Forecasting temporary sequences, Gliwice: Publishing Company of the Silesian University of Technology.
2. **Dittmann, P., Szabela-Pasierbińska, E., Dittmann, I. Szpulak, A.** 2011. Forecasting in sales and financial management of a business. Wolters Kluwer Polska Sp. Z o.o. Warsaw.
3. **Sokołowski, A.** 2016. Forecasting and analysis of time series. Training materials. StatSoft Polska. Cracow.
4. StatSoft. (2006). Electronic Manual of PL Statistics, Cracow, [online cit.: 2018-05-22]. Available from: http://www.statsoft.pl/textbook/stathome.html
5. Data on accidents collected and made available by the Polish Road Safety Observatory

New Possibilities of Electric Taxiing for Aircraft

J. Hospodka

ČVUT v Praze, Ústav letecké dopravy, Horská 3,11001, Praha, Czech Republic, E-mail: hospojak@fd.cvut.cz

Abstract

Electric taxiing system for aircraft is new tool how to achieve several important goals. Main advantages are increased safety of operations, reduced operational costs and mitigation of environmental impacts. This paper is focused on several possibilities how to implement ETS systems in the aerodrome operational environment. We discuss possibilities to use battery systems and ground based systems for distribution of electric energy during taxiing. Also we try to estimate impacts of such systems on fulfilment o goals of the Flightpath 2050 EC report. The Flighpath 2050 sets the goal to have emission completely free taxiing by the 2050. To achieve this goal there should be some first steps implemented in nearest future.

KEY WORDS: *eletric taxiing, handling,airport*

1. Introduction

Electric taxiing will be possible in near future by Electric taxi systems (ETS), which use electric power generated by aircraft to power electric traction engines equipped on landing gear. Despite the fact that none of the systems is certified for operation, this topic is already discussed and high potential of these systems is predicted. The document Flightpath 2050 – Europe´s vision for aviation [7] identifies electric taxiing as one of the key areas to focus further aviation development. In this document in the chapter "Protecting the environment and the energy supply" is stated as a goal for aviation research: „Aircraft movements are emission-free when taxiing". In this paper we will dissertate on how this goal may be achieved by ETS.

2. ETS Description

ETS systems are developed by different companies with several identical aspects. As examples we will refer to ETS developed by Wheeltug Company and ETS called EGTS developed by Safran. Both these system use electric power generated by aircraft´s APU to power electric traction system equipped on landing gears. Pilot has full control of this system from cockpit and energy consumption should allow to shut down main engines completely, when ETS is used for taxiing. Main difference between these systems is that Wheeltug powers nose wheel only [1], and EGTS [2] powers main landing gears. There also other differences such as voltage used, cooling, braking abilities and mass of the system. Difference in the solution of which gear is powered is significant, as it is influence torque of the system, but also its mass.

Benefits of ETS are straightforward. ETS decreases fuel consumption, during taxiing, because electric engines have better fuel efficiency than main turbofan fines, even when is for taxiing used only one of the main engines. ETS systems also decrease handling costs because aircraft don't need any pushback. Because aircraft don´t use main engine during taxi there is savings in maintenance cost of engines both for planned and unplanned maintenance. Unplanned maintenance costs decrease is even more significant when foreign object damage (FOD) costs are taken into account. Also because of greater manoeuvrability of aircraft equipped with an ETS, there could be some time savings during the aircraft turnaround. But these time savings are greatly dependant on how manoeuvrable the ETS system will actually be, and if airport is equipped to handle aircrafts equipped with an ETS.

3. Manoeuvrability of ETS with Possibility of Parallel Parking a Terminal

Because of ale ETS systems are only in test operations there no certified data about performance of these systems. Therefore, for estimation of ETS performance have to be used model. We used outputs of model presented by Huang [3]. The main conclusion of Huang [3] is that an ETS is for narrow body aircraft feasible to allow all basic taxiing operations. For Wheeltug system „the turning angle of the aircraft body and the turning time are almost linearly related, which conforms to the yaw angle of civil aircraft during yawing process". For EGTS system is benefit that when main wheels are powered and controlled differentially, therefore turning radius will be even lower.

At present time (early 2018) there are no actual data from airport operations for any ETS yet, so we have to base our presumptions only on estimates and models. But it seems that from point of view of manoeuvrability an ETS system will achieve at least similar outputs as conventional taxiing operations. If we would taken into consideration proclamations made by the ETS manufacturers that their system will outperform traditional taxiing, ETS system may offer more savings especially in area of time reduction for the turnaround time. But if an ETS equipped aircraft would use tradi-

tional operational procedures the time savings possibilities are limited only to saving couple of minutes during pushback.

If potential of ETS systems for time savings should be maximized it would be necessary to provide changed conditions in airport standings layout. If manoeuvrability of aircraft would allow it, and if layout of standing and terminal would allow it, the best possibility how to achieve time reduction is parallel parking to airport terminal. Parallel parking to airport terminal would allow faster handling operations with possible time savings in tenths of minutes. Precise estimations of these time savings are yet to be done but roughly, because of possibility to use two boarding bridges, the most critical part of the turnaround process, boarding and deboarding of passengers may decrease about one third. This may represent time saving about 15 minutes for narrow body aircraft. This estimated time saving can be considered as significant.

Second aspect of this turnaround time reduction for air transport operators are negative effects which would be transferred on airport operators. Greatest negative aspect is necessity to adapt existing terminal standing for ETS operations. Besides construction costs there are concerns about ETS parallel standing dimensions. Based on AC 150/5300 – 13A [4] the recommended width of the stand is 162ft for narrow body aircraft and based on presumption that manoeuvrability of ETS system will be at least same as conventional taxiing manoeuvrability, we estimate that for most types of narrow body aircrafts it would be necessary to adapt dimension of standing to be able to accommodate ETS equipped aircraft standing parallel to the terminal. The estimated increase in the dimension of standing depends also on type of used boarding bridges and their position with respect to door position on aircraft. With these key aspects taken into account w presume that necessary change in dimension of stand would be at least 30ft. Increased dimension of stand may lead to decreased number of stands because of limited space beside the terminal. On the other hand if it would be possible to reach expected time savings and therefore turnaround time of aircraft t would decrease, the decreased number of stands don´t have to lead to decreased capacity of whole terminal.

Outgoing question remains if it would be possible that the same stand can be used by aircraft with ETS and also by normal aircraft. The Position of bridges, taxiway markings and handling equipment space distribution can make operation of both types on same stand difficult. Especially when radio frequency band 1030/1090 MHz ATS services typically use are already heavily congested [10]. Therefore, usage of ETS as control mechanism for ATS is reaching issue of congested electromagnetic spectrum in airdromes.

4. Zero Emissions

As mentioned before, the goal of Flightpath 2050 is to achieve taxiing without emission. The ETS systems, at its present state, do not achieve this goal, because they need APU in service. APU fuel consumption is lower than fuel consumption of main engines on taxi setting but for narrow body aircraft fuel consumption of APU can still reach about 130kg of fuel per hour. To reach zero emission taxiing we would have to use either different taxi system, such as taxibot [6], or we have to power the ETS system from batteries.

In next part of this article we estimated if batteries would be suitable for powering of ETS for narrow body aircraft. In table 1, there are estimated values of power consumption for different situations during taxi

Table 1

Power consumption estimations for narrow body aircraft

Operation	Power [kw]	Average taxi time [s]	Maximal taxi time [s]
Stable velocity 3 m/s	15	780	800
Slow acceleration 0,3 m/s2	30	40	300
Fast acceleration 1 m/s2	60	40	40
Maximal acceleration	80	10	10
Deceleration (without using brakes)	50	30	150
Time total		900	1800

Total power consumptions depends on taxi duration. Duration of taxi varies based on airport dimensions, traffic density meteorological conditions and more other variables. Because we presume that batteries are to be recharged during flight we have to only optimize battery capacity for one operation (either taxi in or taxi out) and because taxi out time is typically longer we have to optimize battery capacity based on energy consumption during taxi out.

According to data accessible from Eurocontrol [5], 99% of taxi out operations on most of airports worldwide is less than 30 min with average about 15 minutes. For our basic estimate of necessary capacity of batteries we estimated times remarked in table 1. Times are based on presumption that taxi time near to maximal taxi time is typically connected with high traffic density which leads to increased number of acceleration events during taxi.

Therefore, computed amount of energy required for average taxiing operation (15 min) is 17 600 kJ and for maximal taxi time (30 min) is 31 700 kJ. With electric energy density of different batteries, stated in table 2. Based on values from table 2 it can be stated that space density of batteries necessary for ETS are not an issue. On the other hands mass of batteries might bring an issue.

Table 2

The energy density of different types of batteries

Battery type	Kilo Joules/kg	Wh/liter
Lead-acid	146	100
Alkaline long-life	400	320
Carbon-zinc	130	92
NiMH	340	300
NiCad	140	140
Lithium-ion	460	230

Based on the table2 the estimated mass of the additional batteries necessary for zero emission taxiing would be at least 100kg. This additional mass of the aircraft would increase the fuel consumption during every flight hour. Estimated additional fuel consumption is 2 kg of fuel per hour of a flight for A320 – based on Eurocontrol [8]. This additional fuel consumption makes the battery usage for taxiing arguable from the point of both environment and economy. Based on data from [9] we may estimate that average block time is about 10,5 hours daily with 3.7 departures daily. It makes additional fuel consumption 21 kg of fuel daily, due to additional mass of batteries. On the other hand we will save part of the fuel during taxi because theoretically we may recharge the batteries while using ground power source. But even if we presume that the energy from ground source is completely „green“ and „free“ it covers only half of energy. The electric energy for taxi in is necessary to recharge from on board sources – main engines or APU.

Therefore, we will spare fuel only for taxi out. As example APIC APS3200 APU used by most A320 aircraft has maximal output 90 kVA. With average power consumption from table1 we can estimate that energy necessary for 15 minutes taxi represents 21% of APU energy output, therefore the consumption of APU to generate enough electricity for taxiing is roughly ((130 kg per hour / 4) * 0,21) 7 kilograms of fuel. With 3,7 [9] departures per day, the fuel saves by not using APU and ether using batteries for taxiing is about 26 kilograms of fuel. Therefore, the fuel saving is negligible and environmental impacts are nearly same only moved from airport to other areas.

5. Conclusion

The ETS systems will bring many positive changes into ground operations of many aerodromes. To ensure that potential of these systems can be fully used it would be necessary to change the layout of standings. With these changes done it is very probable that ETS systems will have positive economic effect on air operators which will use them. Lowered maintenance costs as well as reduce turnaround time are probable positive effects which go with reduced fuel consumption.

On the other hand, impact on environment will be limited only on decreased fuel consumption due to not using main engines. From chapter 4 it seems that ETS systems doesn´t have potential to reach completely emission free taxiing operation. To achieve this goal, it would be necessary to use batteries with much higher energy density than the density which is achievable today. If any aerodrome would really aim for emission free taxiing it would be necessary to focus on a different solution.

References

1. Wheeltug [online cit.: 2018-04-22].http://www.wheeltug.gi/about.php.
2. Safran [online cit.: 2018-04-22].https://www.safran-landing-systems.com/systems-equipment/electric-taxiing-0.
3. **Huang, A.; Mingyang, A. Nie.; Hong, A. Zhang; Ming, T.** 2018. Analysis of ground handling characteristic of aircraft with electric taxi system. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering http://journals.sagepub.com/doi/abs/10.1177/0954407018764163
4. AC 150/5300 – 13A [online cit.: 2018-04-22] https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/ 150_5300-13
5. CODA report [online cit.: 2018-04-22] http://www.eurocontrol.int/articles/central-office-delay-analysis-coda.
6. **Hospodka, J**. 2014. Electric taxiing – Taxibot system MAD - Magazine of Aviation Development 2(10): 17-20. ISSN 1805-7578.
7. EUROPEAN COMMISSION -Directorate-General for Research and Innovation - Flightpath 2050 -Europe’s Vision for Aviation -Report of the High Level Group on Aviation Research Directorate General for Mobility and Transport https://ec.europa.eu/transport/sites/transport/files/modes/air/doc/flightpath2050.pdf
8. EEC Technical/Scientific Report No. 2009-009 Eurocontrol, Base of Aircraft Data (BADA) Aircraft Performance Modelling Report, 2009. Eurocontrol Experimental Centre 2009. accessible on: http://www.eurocontrol.int/sites/default/files/content/documents/sesar/bada-aircraft-performance-modelling.pdf.
9. Airline data project [online cit.: 2018-04-22]. http://web.mit.edu/airlinedata/www/Aircraft&Related.html
10. **Pleninger, S.; Lipták, T.** The Issue of Aviation Cooperative Surveillance Systems RF Band Congestion In: Transport Means 2017 - Proceedings of the International Scientific Conference. Kaunas: Technical University, 2017. pp. 286-290. ISSN 1822-296X.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Research of Railway Crashed Stone Use of 40 –70 mm Fraction

O. Pshinko[1], O. Patlasov[2], V. Andrieiev[3], M. Arbuzov[4], O. Hubar[5], O. Hromova[6], R. Markul[7]

[1]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, 49010, Dnipro, Ukraine, E-mail: pshinko@r.diit.edu.ua, dnuzt@diit.edu.ua*
[2]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, 49010, Dnipro, Ukraine, E-mail: am_patlasov@ukr.net, patlasov@ipo.diit.edu.ua*
[3]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, 49010, Dnipro, Ukraine, E-mail: avs_diit@ukr.net*
[4]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, 49010, Dnipro, Ukraine, E-mail: 10max@ukr.net*
[5]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, 49010, Dnipro, Ukraine, E-mail: neris@ua.fm*
[6]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, 49010, Dnipro, Ukraine, E-mail: eleana2008@i.ua/*
[7]*Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, 49010, Dnipro, Ukraine, E-mail: guarangamr@gmail.com*

Abstract

The results of the conducted researches on operating, physical and mechanical properties of crushed stone of 40-70 mm fraction are presented in the article as well as the results of the comparison of the given fraction with the fraction of 25-60 mm and determination of the former fraction usage for the ballast with the purpose of more rational fund use during railway repair works.
The conducted researches of 40-70 mm fraction of crushed stone allowed receiving:
– actual values of technical indices of the product and adopted technical decisions;
– conformity of the product with the operating conditions as well as physical and mechanical properties during track maintenance;
– ability to perform tests;
– comparison of physical, mechanical and operational properties of crushed stone of 40-70 mm fraction with the crushed stone of 25-60 mm fraction.
KEY WORDS: *railway track, ballast crushed stone, crushed stone of 40-70 mm fraction, crushed stone of 25-60 mm fraction, operating properties of crushed stone, physical and mechanical properties of crushed stone.*

1. Introduction

The crushed stone of 40-70 mm fraction is intended for the arrangement of the ballast layer on railways, which provides vertical and horizontal stability of the track.

On general railways with soil subgrade (more than 99% of the total length of railways), the upper structure of the track with a ballast layer is the main construction which usage is conditioned both technically and economically.

The ballast layer consisting of granular materials is one of the most important elements of the upper structure of the railway. It provides vertical and horizontal stability of the track. The structure and quality of the ballast layer depend on: the general condition of the railway, the level of permissible train speeds, the service life of the elements of the upper structure of the track (rails, fastenings, sleepers), the cost of the current maintenance of the track and the entire system of its repairs.

According to [1-3], the ballast layer must:

– take pressure from sleepers (girders on turnouts) and distribute it practically evenly on possibly larger area of the subgrade;

– provide the stable design position of the rail-sleeper grid during operation;

– provide the possibility of track correction in the profile and plane due to the ballast layer (by track tamping, straightening) to compensate inevitable residual deformations;

– quick drainage from the ballast prism and from the main site of the subgrade, prevent overwetting and overdrying of the upper layer of the soil of the subgrade, the loss of its bearing capacity (in the spring) and counteract upheaval (in winter);

– participate in the formation of the optimum elasticity of the underrail base, especially during reinforced sleepers' usage.

In accordance with the requirements of the national standard [4], ballast fractions of 25-60 mm are used for ballasting the main roads of general railways. Crushed stone is obtained by crushing rock. Depending on the type of initial

rock, crushed stone can be made of: rock formations (100% of crushed particles); of boulders and gravel (crushed grains Not less than 50%).

On the railways of general use, crushed stone fractions of 25-40 mm and 25-60 mm are intended for ballasting of main tracks; crushed stone of 5-25 mm fractions is used for ballasting station and access tracks.

The mixture of fractions is used to fill rationally the intergranular void and evenly redistribute the load from the rolling stock on the rail-sleeper grid through the ballast crashed stone to the soil.

At present, according to the current standard, the use of crushed stone for track ballasting with the fraction larger than 60 mm is allowed up to 5%. The crushed stone of large fractions of 25-60 mm and 40-70 mm was used up to 1991, and in connection with the conversion of crushing enterprises to two- and three-degree crushing production, the crushed stone of 40-70 mm fraction was not practically used for track ballasting. However, due to energy saving in the country, including the railway industry, there was a need to reduce stages of stone crushing for track ballasting and conducting the researches on crashed stone of 40-70 mm fractions instead of 25-60 mm fractions for railways.

2. Methods of Testing, Parameters Measurement and Their Comparison

To compare physical and mechanical properties of crashed stone fractions of 40-70 mm (Fig. 1) and 25-60 mm (Fig. 2), tests of selected samples were performed.

Fig. 1 Contaminated crushed stone fraction of 40-70 mm

Fig. 2 Contaminated crushed stone fraction of 25-60 mm

The following physical and mechanical properties of the crushed stone ballast were determined according to national standards:

– the grain composition and the content of particles less than 0.16 mm according to [4] (paragraph 6.2);
– average bulk density and voidness of crushed stone according to [5] (paragraphs 4.16 and 4.17);
– the content of dust, organic impurities and clay in lumps according to [5] (paragraphs 4.5, 4.14 and 4.6);
– the strength of crushed stone with regard to crushing and rubbing indices according to [5] (paragraphs 4.8 and 4.10).

The conformity of certain physical and mechanical properties of crashed stone ballast to the requirements of the current standard was estimated [4].

2.1. Determination of Grain Composition and the Content of Particles Less than 0,16 mm

The main characteristic of crushed stone, which determines its physical, mechanical and operational properties as well as the possibility of application as a ballast material, is its grain composition that must conform to the standard. For this purpose, in accordance with the requirements of the national standard for test methods, the crushed stone was dried in a drying cabinet to a constant mass (G). The dried sample of crashed stone was poured into a vessel, poured over with water and stirred vigorously. After mixing, the formed turbid water was drained through safety sieves with apertures of 5 mm in diameter, with meshes 1 and 0.16 mm, and the crushed stone was poured onto the upper sieve and washed with clean water until the drained water became transparent. The washed crashed stone (Fig. 3 and Fig. 4) left on sieves with apertures of 5 mm in diameter and meshes 1 and 0,16 mm, was combined and dried in a drying cabinet to a constant mass (G_0).

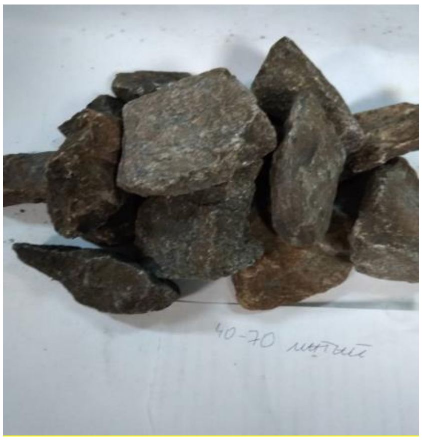


Fig. 3 Washed crashed stone of 40-70 mm fraction

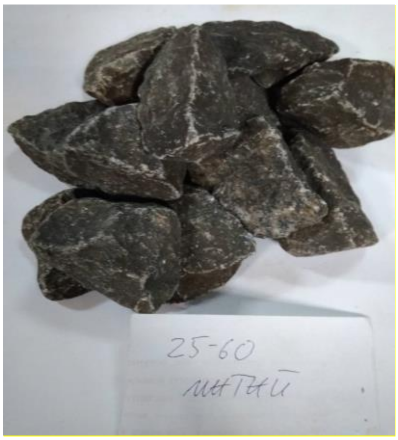


Fig. 4 Washed crashed stone of 25-60 mm fraction

The dried sample is sieved through a set of sieves (Fig. 5) with apertures of the size:

– 70; 60; 40 and 25 mm – for crashed stone fractions 25 to 60 mm;

– –60; 40 and 25 mm, as well as a gauge-calibre with a diameter of 90 mm – for crushed stone fractions of 25 to 70 mm.

Fig. 5 The set of sieves for granulometric determination of crashed stone composition

The granules of crashed stone, which did not pass through the gauge-calibre, residues on each sieve and crashed stone, which passed through the sieve with an aperture of 25 mm in diameter, were weighed separately.

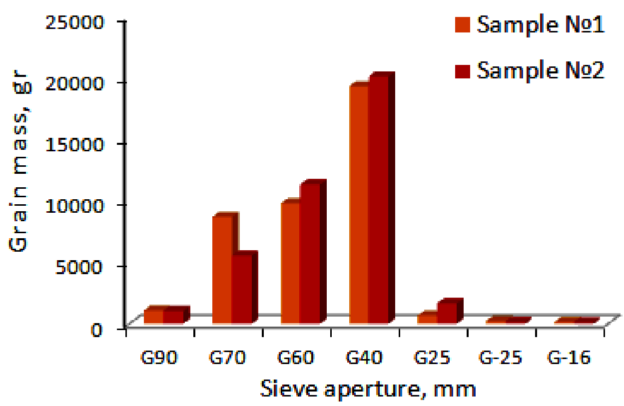


Fig. 6 Fraction of 40-70 mm. Sample No1: G = 40,026 kg. Sample No2: G = 40,079 kg.

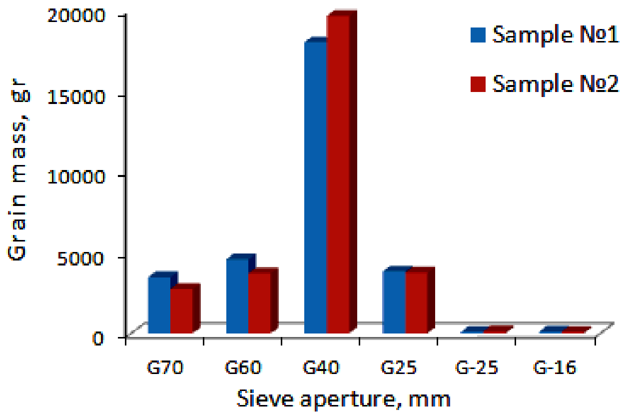


Fig. 7 Fraction of 25-60 mm. Sample No1: G = 30,073 kg. Sample No2: G = 30,069 kg

Mass of crashed stone grains that did Not pass through the gauge calibre (G_{90}), residues on sieves with holes in

the diameters of 70, 60, 40, 25 (G_{70}, G_{60}, G_{40}, G_{25}), and the mass of crushed stone that passed through sieves with apertures in diameters of 25 mm and 0.16 mm (G_{-25}, $G_{-0.16}$) are shown in Figures 6–7.

The comparison of grain composition of fractions of 40-70 mm and 25-60 mm according to the requirements [4] is given in Table 1 (average values of the obtained indices for two samples of each fraction are used).

Table 1

Grain composition of fractions of 40-70 mm and 25-60 mm according to national requirements DSTU BV.2.7-204:2009

<table>
<tr><th colspan="2" rowspan="4">Size of grain fraction, mm</th><th colspan="4">Amount of grains</th><th rowspan="4">Total residue on the sieve with the aperture in diameter of 40 mm, % per mass</th></tr>
<tr><th colspan="2">Larger than upper nominal size</th><th colspan="2">Smaller than lower nominal size</th></tr>
<tr><th rowspan="2">Within the size, mm</th><th rowspan="2">% per mass, not more</th><th colspan="2">% per mass, Not more</th></tr>
<tr><th>Totally</th><th>Including grains with the size less 0,16 mm</th></tr>
<tr><td rowspan="4">40-70</td><td rowspan="2">According to ND*</td><td>60...70</td><td>5</td><td>5</td><td>1,5</td><td rowspan="2">25 to 75</td></tr>
<tr><td>over 70</td><td>0</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Test result</td><td>60...70</td><td>26,31</td><td>0,8/3,7</td><td>0,33</td><td rowspan="2">96,3</td></tr>
<tr><td>over 70</td><td>20,5</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Compliance with ND requirements</td><td>According to separate components</td><td></td><td>doesn’t meet</td><td>meets</td><td>meets</td><td>doesn’t meet</td></tr>
<tr><td>Total</td><td colspan="5">doesn’t meet</td></tr>
<tr><td rowspan="4">25-60</td><td rowspan="2">According to ND</td><td>60...70</td><td>5</td><td>5</td><td>1,5</td><td rowspan="2">25 to 75</td></tr>
<tr><td>over 70</td><td>0</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Test results</td><td>60...70</td><td>13,8</td><td>0,7</td><td>0,32</td><td rowspan="2">86,7</td></tr>
<tr><td>over 70</td><td>10,3</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Compliance with ND requirements</td><td>According to separate components</td><td></td><td>doesn’t meet</td><td>meets</td><td>meets</td><td>doesn’t meet</td></tr>
<tr><td>Total</td><td colspan="5">doesn’t meet</td></tr>
</table>

Notes: ND* – Normative Documents

The grain composition of the crashed stone ballast of the selected samples of fractions of 40-70 mm and 25-60 mm does not meet the requirements [4]. This indicates the non-compliance with the requirements for grain size which leads to the increase of voidness and litteriness of the ballast.

2.2. Determination of Average, Bulk Density and Voidness of Crushed Stone

2.2.1. Determination of Average Density of Crushed Stone

The physical properties of crashed stone characterize its interaction with the environment and determine the mechanical and operational properties. To determine the average density in laboratory conditions, a simplified method of hydrostatic weighing is used. The volume of the sample is estimated by the amount of water poured out into a measuring glass from the volumeter after water-saturated sample immersion into it. The specified characteristics of the average density are given in Tables 2-3.

Table 2

Determination of the average density of the ballast crashed stone of 40-70 mm fraction

Sample No	Mass of dry sample, (m_c), gr	Volume of water-saturated sample, ($V_{зр}$), cm^3	Average density of crashed stone, (ρ_c), gr/cm^3
1.	200	77,4	2,58
2.	264	99,95	2,75
3.	218	81,63	2,67
4.	143	54,2	2,64
5.	135	50,5	2,67
Average value			**2,7, gr/cm^3**

Table 3

Determination of the average density of the ballast crashed stone of 25-60 mm fraction

Sample No	Mass of dry sample, (m_c), gr	Volume of water-saturated sample, ($V_{зр}$), cm^3	Average density of crashed stone, (ρ_c), gr/cm^3
1.1	183	68,7	2,66
2.1	195	69,95	2,79
3.1	255	89,4	2,85
4.1	200	73,4	2,72
5.1	167	64,5	2,59
Average value			**2,72, gr/cm^3**

The average density of the analyzed crashed stone of the ballast is 2,7 gr/cm^3 for fraction of 40-70 mm and 2,72 gr/cm^3 for fraction of 25-60 mm that is within standard – 2,5 to 2,9 gr/cm^3.

2.2.2. Determination of Bulk Density of Crushed Stone

The bulk density of crashed stone is determined by weighing of a certain volume of crashed stone of the given fraction dried to a constant mass.

The crushed stone in the volume providing the test performance is dried to a constant mass. The results of determining the bulk density of crashed stone of fractions of 40-70 and 25-60 mm are given in Table 4.

Table 4

The bulk density of crashed stone of 40-70mm and 25-60 mm fraction

Fraction, mm	Sample No	Weight of the measuring cylinder (m), kg	Weight of the measuring cylinder with the material ($m1$), kg	Bulk density of crushed stone (ρ_n), kg / m3	
40-70	1	3,47	69,2	1315	1320
	2		69,8	1326	
25-60	1		72,1	1373	1360
	2		71,5	1361	

The bulk density of the researched crashed granite of the ballast is 1320 kg / m3 for fraction of 40-70 mm and 1360 kg / m3 for fraction of 25-60 mm, which is within the standard 1300 to 1450 kg / m3.

2.2.3. Determination of Crushed Stone Voidness

Within the limits of the research of physical and mechanical properties of the ballast crashed stone, the voidness of crushed stone fractions of 40-70 mm and 25-60 mm was determined. Voidness is characterized by the presence of cavities (voids) between the grains in loose materials (sand, crashed stone, etc.) and is determined as a percentage of the total volume of material or in parts of the unit. The results of crushed stone voidness determination of fractions of 40-70 and 25-60 mm are given in Table 5.

Table 5

Voidness of crashed stone of 40-70 and 25-60 mm fractions

Crashed stone fraction, mm	Average density of the material, gr/cm^3	Bulk density of the material, gr/cm^3	Voidness of crashed stone, %
40-70	2,7	1320	51,1
25-60	2,72	1360	50,0

The results of the tests indicate that crashed stone of a large fraction has greater voidness.

2.3. Determination of Crushed Stone Strength with Regard to Crushing Index

Crushing ability of crushed stone was determined by the degree of grains destruction in compression in a cylinder (Fig. 8) and characterizes the mechanical properties of crushed stone, namely, the ability to withstand the operating load without destroying.

Fig. 8 Cylinder for determining crushing ability of crushed stone

According to the crushing index, the grade of crashed stone was determined according to [6] (Section 4.4.1) and is shown in Table 6.

Table 6

The grade of crashed stone determined according to the crushing index

The grade of crashed stone according to the crushing index	Crushing index (*Cr*) according to mass lost, %
1400	to 12
1200	12...16
1000	16...20
800	20...25
600	25...34

The results of determining the strength of crushed stone fractions of 40-70 and 25-60 mm according to the crushing index are given in the Table 7.

Table 7

Determination of crashed stone strength according to the crushing index

Crashed stone fraction, mm	Sample No	Sample mass of crashed stone, (m), kg	Residual mass on the controlling sieve (m_1), kg	Crushing index (*Cr*), %	Average crushing index (*Cr*), %	The grade of crashed stone according to the crushing index
40-70	1	319	287	10	11,2	1400
	2	324	284	12.35		
25-60	1	312	285	8.65	10,1	1400
	2	329	291	11.55		

The tests results indicate high mechanical strength of crushed stone of both fractions.

2.4. Determination of Crushed Stone Strength According to the Rubbing Index

An important characteristic of the ballast crashed stone is its strength according to the rubbing index, which characterizes wear resistance of crushed stone under operating conditions. The crashed stone grade according to its strength, determined by its rubbing property in a polygonal drum (Fig. 9), is established according to the data of the Table 8.

According to the standard, prepared sample of crashed stone was loaded into a polygonal drum along with steel balls; the drum lid was secured and the drum was rotated at the speed of 30-33 rpm.

Fig. 9 The polygonal drum for crashed stone strength determination with regard to the rubbing index

Crashed stone grades determined according to the rubbing index with the use of the polygonal drum are given in the Table 8.

Table 8

Crashed stone grade determination according to the rubbing index

Crashed stone grade	Rubbing (mass lost), %
Crashed stone of fraction of 5 to 40 mm and 25 to 60 mm	
C 20	up to 20 inclusively
C 40	over 20 to 40
C 50	40-50

The results of crashed stone strength determination of fractions of 40-70 and 25-60 mm according to the rubbing index in the polygonal drum are given in the Table 9.

Table 9

Crashed stone strength determination according to the rubbing index in the polygonal drum

Fraction, mm	Sample No	Crashed stone sample mass, (m), kg	Total residual mass on the sieves 5 and 1.25, (m_1), kg	Rubbing (R), %	Average rubbing (R), %	Crashed stone grade according to the rubbing index
40-70	1	10,035	(8,270+0,252)=8,522	15,08	15,9	C20
	2	10,027	(8145+0,207)=8,352	16,7		
25-60	1	10,014	(8495+0,305) =8,800	12,12	14	C20
	2	10,021	(8157+275) =8,432	15,86		

2.5. Determination of Crashed Stone Contamination

The results of determining the contamination of selected crushed stone samples of fractions of 40-70 and 25-60 mm are shown in Table 10.

Table 10

Determination of selected crushed stone samples contamination of fractions of 40-70 and 25-60 mm

Fraction, mm	Sample No	Total mass of crashed stone, (Q), kg	Part of the sample mass, which passed through the sieve with the aperture of 25 mm in diameter, (q_{25}), kg	Crashed stone contamination (q), %	
				For sample	Average for fraction
40-70	1	40,03	0,363	0,91	0,79
	2	40,08	0,265	0,66	
25-60	1	30,07	0,188	0,63	0,67
	2	30,07	0,211	0,7	

3. Research of Operational Parameters of the Track with Crushed Stone Fraction of 40-70 mm

One of the main parameters, which is substantially influenced by the work of the crashed stone layer, is the geometrical position of the rail track. With the deviation of this parameter from the normative value, there is an increase in the dynamic interaction of the track and rolling stock, which significantly influences the intensity of the accumulation of residual deformations in the track. At the same time, the frequency of deviations removal increases, and the terms of malfunctions elimination are reduced [7]. The deviations in geometric parameters from the normative values have their degree of influence. There are five degrees of deviations for all parameters of rail track keeping depending on their size and length. Each degree of deviation from the norms of track keeping is estimatedin points [8].

The deviations of the first degree include shifts within the tolerances, under which the safety and smoothness of the trains are ensured. Under such conditions, the established train speeds do not decrease and work is not required to eliminate deviations.

The deviations of the second degree include shifts that do not require the established speed reduction and do not threaten trains safety, but affect the smoothness of trains' movement. They are the reason for assignment and conducting planned and preventive work.

Single deviations of the third degree are referred to those that do not require reduction of the established speed and do not threaten the safety of trains, but affect the smoothness of trains' movement and the intensity of residual track deformation accumulation. They are the reason for assignment and conducting planned and preventive work.

The deviations of the fourth degree are referred to those, in the presence of which and at established speeds, the smoothness of trains decreases, which leads, in its turn, to intensive accumulation of residual deformations of the track. Such deviations are eliminated as a matter of priority.

The deviations of the fifth degree include shifts that lead to the increase of interaction forces of the track with rolling stock to such critical values that, in the presence of adverse combinations with deviations in the maintenance and loading of rolling stock, violations of train driving regime and other conditions, can result in very rapid growth of deformation and to the threat of safety trains movement.

For deviations of III-V degrees, penalty points are awarded. The deviations of the second degree, detected by the track measurement cars, are taken into account only for performance of planning-preventive track works. Penalty points are also awarded for deviations in the plane of the second degree at speeds exceeding 140 km / h.

Due to the increased dynamic impact of rolling stock on the track in the places of deviation of the fifth degree, as well as in the combination of several deviations of III-V degrees (distortions, subsidence, shifts in the plane), when detecting such places, it is necessary to take measures immediately to ensure the safety of trains movement.

The compliance of the priority and timing of deviations elimination with the rules for track maintenance and trains' movement, when detecting deviations, ensures safe passage of the rolling stock.

The inspection of the main railways should be performed by the track measurement car, and the receiving-sending tracks should be carried by the track-testing bogie.

Equipping of track measuring devices and enterprises of the track economy with modern computer technology allows to improve significantly the methods of estimating the geometry of the rail track and to expand the range of practical tasks being solved by these methods. The parameters of the rail track measured and recorded by the track measurement car include: the reciprocal position of track rails in height (level), local subsidence (hills and hollows) of each track rail, gauge, and position of track rail with regard to the direction in the plane.

During the research, two track sections were selected, on which the state of geometrical parameters of the railway track according to the recorded data of the track measurement car was analyzed. The operational characteristics of the sections are as follows:

Track section number 1:

– Load capacity – 52,7 mln.t. km gross / km per year; passed tonnage – 88,1 mln. t. gross; crushed stone fraction 40–70 mm (km 133 peg 5–10; km 134 peg 1–4; km 136 peg 5–10; km 137; 138 peg 1–10; km 140 peg 1–8);

– Load capacity – 52,7 mln. t. km. gross / km per year; passed tonnage – 106.46 mln. t. gross; crashed stone fraction 25–60 mm (km.134 peg 5–10, km 135 peg 1–10, km 136 peg 1–5).

Track section number 2:

– Load capacity – 51,8 mln. t. km. gross / km per year, passed tonnage – 68,1 mln. t. gross; crashed stone fraction 40-70 mm (km 320 peg 3–10, km 321 peg 1–10, k 322 peg 1 – 10, km 323 peg 1 – 10);

– Load capacity – 51,8 mln. t. km. gross / km per year, passed tonnage – 68,1 mln. t. gross; crashed stone fraction 25–60 mm (km 324 peg 1–10, km 325 peg 1–10, km326 peg 1–5, km326 peg 1–6).

Figs. 10-11 show the general assessment of the railway track state in points measured and recorded by the track measurement car on the two selected sections.

As we see from Figs. 10 and 11, the number of points for each kilometre does Not exceed 40 (as an exception, 133 km – 51 points, and 140 km – 61 points (track section number 1); 324 km – 56 points (track section number 2)). This suggests that the size of the crash stone fraction does not practically affect the geometrical state of the railway track.

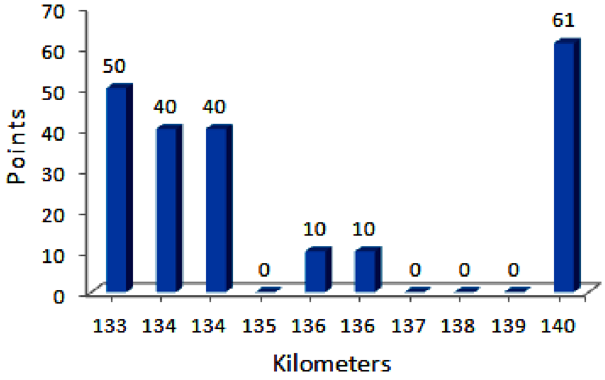


Fig. 10 Parameters of track state on the section No 1

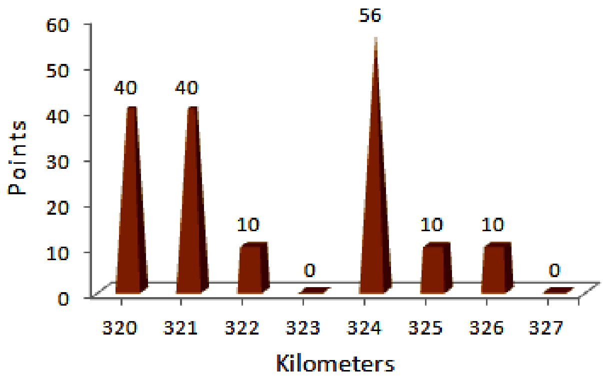


Fig. 11 Parameters of track state on the section No 2

4. Conclusions

According to the data of physical and mechanical tests of crushed stone fractions of 40–70 mm and 25–60 mm, the experimental parameters of the average and bulk density, voidness, crushing and rubbing properties, the content of dust, organic impurities and clay in the lumps are within the current standard for the ballast crushed stone [4].

Due to the increased voidness up to 51.1–50% of the ballast crushed stone of fraction 40–70 mm, its contamination is relatively larger and makes up 0.79% in the selected samples for the fraction of 40–70 mm and 0.67% for the fraction of 25–60 mm. In the selected samples of both fractions, the content of grains of the lamellar form is increased and numbers about 25%, however, when comparing their mechanical properties, the crushing and rubbing indices correspond to high grade of crashing stone – Dr1400, where rubbing index is C20.

Taking into account the foregoing, subject to the requirements of the granulometric composition, crushed stone of fraction 40–70 mm can be recommended for railway ballasting as well as crushed stone of fraction 25–60 mm due to the expected economic effect of reducing crushing stages, energy saving and approximate cost reduction of the product from € 5.5 / t for the fraction of 25–60 mm up to € 4.8 / t for the fraction of 40–70 mm, however the economic effect may be revised taking into account local conditions.

After analyzing crushed stone ballast performance of fraction 40–70 mm on separate sections of railways with the same load capacity, and after comparative analysis of it with the crushed stone ballast performance of fraction 25–60 mm and their influence on the parameters of track state (in terms of points), it can be concluded that the stability of the track on the crashed stone ballast with the fraction 40–70 mm can be considered similar to the track on the crashed stone ballast with the fraction 25–60 mm. Thus, it is possible to recommend using crushed stone of fraction 40–70 mm for the ballast of the railway track as well as the fraction 25–60 mm.

References

1. Rules of technical operation of the railways of Ukraine, approved by the order of the Ministry of Transport of Ukraine dated December 20, 1996, No. 411 and registered with the Ministry of Justice of Ukraine on February 25, 1997, No. 50/1854.
2. Instruction on the arrangement and maintenance of railways of Ukraine (CP / 0269) / E. I. Danilenko, A. M. Orlovsky, M. I. Karpov, V. O. Yakovlev, V. V. Rybkin, O. M Patlasov and others / – K .: Transport of Ukraine, 2012. – 358 p.
3. Instruction on safety of trains' movement during the performance of track works on the Ukrainian railways. VND UZ 32.6.03.004-20-12, CP-0273 – K .: SPA"Poligrafservice" Limited, 2012. – 108 p.
4. DSTU B V.2.7-204: 2009 Natural crashed stone for the ballast layer of the railway track. Specifications.
5. STU B V.2.7-71-98 Crashed stone and gravel made of dense rocks and industrial production wastes for construction works. Methods of physical and mechanical tests.
6. DSTU B V.2.7-75-98 Building materials. Crushed stone and gravel, natural and dense, for building materials, products, structures and works. Specifications.
7. Provisions on scheduled maintenance and repair works on railways of Ukraine (CP), 2015. – 150 p.
8. Technical instructions on the assessment of the railway track according to the data of the track measurement cars and ensuring the safety of the trains' movement when deviating from the standards of track maintenance (CP – 0267) / Patlasov O. M., and others. / K .: Transport of Ukraine, – 2012.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Optimization of the Transport of Drinking Water in Extraordinary Events

J. Mihoková Jakubčeková[1], E. Benčíková[2]

[1]*University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, E-mail: julia.mihokova@fbi.uniza.sk*
[2]*Central Military Hospital SNP Ružomberok – Faculty Hospital, ul. Gen. Miloša Vesela 21, 034 26 Ružomberok, E-mail: bencikovae@uvn.sk*

Abstract

The paper focuses on the problem of emergency supply with drinking water. In order to ensure the supply of drinking water to the population, it is possible to use linear programming, which is understood as a quantitative tool for supporting the decision-making process. In supply, it is possible to set basic criteria such as transport costs, mileage, maximum amount of drinking water, etc. The set of boundary conditions, as well as the criterion, depends on the type of decision task. For supply, the boundary conditions may include, for example, the capacity of dispensing points, warehouses, transport capacity of transport means, parameters of the routes being transported, etc.
KEY WORDS: *drinking water, extraordinary events, optimization, transportation*

1. Introduction

At a time when an extraordinary event occurs and the supply of drinking water through water line is disrupted, it is very important that the emergency supply of the population with drinking water is always carried out smoothly and according to established, precisely defined procedures. The supply for the population will mainly benefit from road transport with a suitable intact road network. For each tanker driver is important to have an emergency supply training. In addition to the tanker driver can be another person that involved in emergency supply and carrying out, for example, operations associated with the base evidence, and that person must have received emergency supply training too. We used this way of emergency drinking water supply both for the population and for the animals that are on the cooperatives.

2. Searching for the Shortest Path Between All System Vertices

Under the term supply of the population, it is necessary to understand the emergency supply mainly of basic foodstuffs, namely drinking water, hygienic needs, etc. [1]. The transportation of these commodities will be directed mainly to the selected places of release, but also to the places where are staying the evacuated people.

The supply will be influenced by a number of factors, the most significant, besides the number of persons, can be included:

- Places of water consumption (places of evacuation accommodation, places of water discharge, etc.);
- Quantity and type of vehicles to be used for transport of water;
- Transport routes (their condition with emphasis on patency, choice of shortest distance);
- The size and geographical character of the evacuation area, etc.

In the context of emergency supply, crisis management authorities also need to address the issues of supplying vital food, drinking water, and the like, using different optimization methods. One of their can be also the Clark-Wright method. The method is suitable for determining the optimal amount of basic food, drinking water, etc., which will be delivered to the various places of distribution resp. place of evacuation accommodation. At the same time, it can also be used to determine the shortest possible transport route as follows in the example.

In tackling a concrete example, we focused on optimizing drinking water transport routes in emergency supplying the population as a vital part of human survival in an extraordinary event. Suppose that the minimum need for drinking water in the emergency supply of drinking water in extremely unfavourable conditions will be 10 l per person per day [2].

Requirements for the quantities of drinking water at the individual distribution place are listed in the Table 1: B = 2 500 l, C = 3 240 l, D = 3 410 l, E = 2 560 l, F = 1 600 l, G = 1 400 l, H = 51 670 l, I = 3 960 l, J = 4 970 l, K = 3 550 l, L = 4 250 l, M = 4 660, N = 102 000 l, which we also wrote in Table 4 in the column marked q_i. The capacity of the cisterns, which provide emergency supplies to the population with drinking water, is 33 000 litres, what corresponds 2 × 1 m^3 – drinking water tank (trailer push-cart), 2 × 3 m^3 – drinking water tank MK, 3, 2 × 7 m^3 – car tanker MILCOM 070, 11 m^3 – tanker car CAV – 11. Our task is to find a way of transporting water to meet all requirements but not to exceed the capacity of the means of transport and to keep the distance to the individual places of distribution was at minimal.

The search for the shortest path between all vertices in the network is calculated using the selected method. First, we have created the graph that is shown in the Fig. 1. The individual peaks are highlighted in large print letters of the alphabet from letter B to letter N, which is represent the location of the individual distribution, and the letter A represents the place where the tanks will be filled with drinking water.

Table 1

The need for drinking water for emergency supplies in distribution place in municipalities [3]

Distribution place	Number of inhabitants / animals	Amount of water [l]
B	250	2 500
C	324	3 240
D	341	3 410
E	256	2 560
F	160	1 600
G	140	1 400
H	430 (dairy cows)	49 450
	220 (calves)	2 220
I	396	3 960
J	497	4 970
K	355	3 550
L	425	4 250
M	466	4 660
N	820 (dairy cows)	94 300
	770 (sheep)	7 700

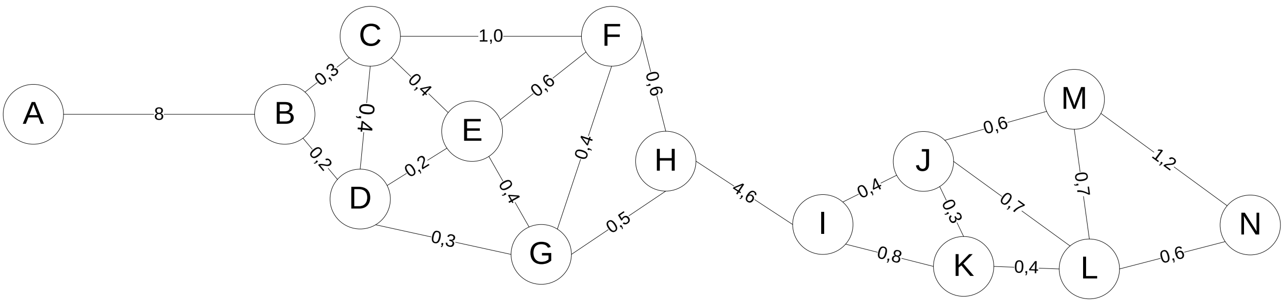


Fig. 1 All roads between the vertices of the network [3]

Table 2

Specified distances between the vertices of the network

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	0	8	M	M	M	M	M	M	M	M	M	M	M	M
B	8	0	0,3	0,2	M	M	M	M	M	M	M	M	M	M
C	M	0,3	0	0,4	0,4	1	M	M	M	M	M	M	M	M
D	M	0,2	0,4	0	0,2	M	0,3	M	M	M	M	M	M	M
E	M	M	0,4	0,2	0	0,6	0,4	M	M	M	M	M	M	M
F	M	M	1	M	0,6	0	0,4	0,6	M	M	M	M	M	M
G	M	M	M	0,3	0,4	0,4	0	0,5	M	M	M	M	M	M
H	M	M	M	M	M	0,6	0,5	0	4,6	M	M	M	M	M
I	M	M	M	M	M	M	M	4,6	0	0,4	0,8	M	M	M
J	M	M	M	M	M	M	M	M	0,4	0	0,3	0,7	0,6	M
K	M	M	M	M	M	M	M	M	0,8	0,3	0	0,4	M	M
L	M	M	M	M	M	M	M	M	M	0,7	0,4	0	0,7	0,6
M	M	M	M	M	M	M	M	M	M	0,6	M	0,7	0	1,2
N	M	M	M	M	M	M	M	M	M	M	M	0,6	1,2	0

We consider the two-way roads in the graph. The first step of the method is from the specified peaks of the individual peaks (Table 1) is to find the shortest distance between all vertices of the network (Table 2). In Table 2, we present the specific determinate values as follows [4]:

- if there is a path from the node i to the node j, write it u_{ij};
- if $i = j$ we do not give any value;
- if there is not a path from the node i to the node j, write it M.

To find the shortest distance, the author's applied the Floyd algorithm, where was choices the matrix for $k = 0$, in form (1), which corresponds to the table 2 [4]:

$$D^k = \left\{ d_{ij}^k \right\} . \tag{1}$$

For $k = k + 1$ was used specific values, in case if $i = j$ we do not give any value, if $d_{ij}^k = M$ and too $d_{ik}^k + d_{kj}^k = M$ for $i,j \neq k$ marked M, in other cases, enter the value $min(d_{ij}^{k-1}, d_{ik}^{k-1} + d_{kj}^{k-1})$. The solution to the method is final, when $k = i$. The values found are shown in the Table 3.

Table 3

Solution using Floyd's algorithm

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	0	8,0	$8,3^{2}$	$8,2^{2}$	$8,4^{4}$	$8,9^{7}$	$8,5^{4}$	$9,0^{7}$	$13,6^{8}$	$14,0^{9}$	$14,3^{10}$	$14,7^{10}$	$14,6^{10}$	$15,3^{12}$
B	8,0	0	0,3	0,2	$0,4^{4}$	$0,9^{7}$	$0,5^{4}$	$1,0^{7}$	$5,6^{8}$	$6,0^{9}$	$6,3^{10}$	$6,7^{10}$	$6,6^{10}$	$7,3^{12}$
C	$8,3^{2}$	0,3	0	0,4	0,4	1	$0,7^{4}$	$1,2^{7}$	$5,8^{8}$	$6,2^{9}$	$6,5^{10}$	$6,9^{10}$	$6,8^{10}$	$7,5^{12}$
D	$8,2^{2}$	0,2	0,4	0	0,2	$0,7^{7}$	0,3	$0,8^{7}$	$5,4^{8}$	$5,8^{9}$	$6,1^{10}$	$6,5^{10}$	$6,4^{10}$	$7,1^{12}$
E	$8,4^{4}$	$0,4^{4}$	0,4	0,2	0	0,6	0,4	$0,9^{7}$	$5,5^{8}$	$5,9^{9}$	$6,2^{10}$	$6,6^{10}$	$6,5^{10}$	$7,2^{12}$
F	$8,9^{7}$	$0,9^{7}$	1	$0,7^{7}$	0,6	0	0,4	0,6	$5,2^{8}$	$5,6^{9}$	$5,9^{10}$	$6,3^{10}$	$6,2^{10}$	$6,9^{12}$
G	$8,5^{4}$	$0,5^{4}$	$0,7^{4}$	0,3	0,4	0,4	0	0,5	$5,1^{8}$	$5,5^{9}$	$5,8^{10}$	$6,2^{10}$	$6,1^{10}$	$6,8^{12}$
H	$9,0^{7}$	$1,0^{7}$	$1,2^{7}$	$0,8^{7}$	$0,9^{7}$	0,6	0,5	0	4,6	$5,0^{9}$	$5,3^{10}$	$5,7^{10}$	$5,6^{10}$	$6,3^{12}$
I	$13,6^{8}$	$5,6^{8}$	$5,8^{8}$	$5,4^{8}$	$5,5^{8}$	$5,2^{8}$	$5,1^{8}$	4,6	0	0,4	$0,7^{10}$	$1,1^{10}$	$1,0^{10}$	$1,7^{12}$
J	$14,0^{9}$	$6,0^{9}$	$6,2^{9}$	$5,8^{9}$	$5,9^{9}$	$5,6^{9}$	$5,5^{9}$	$5,0^{9}$	0,4	0	0,3	0,7	0,6	$1,3^{12}$
K	$14,3^{10}$	$6,3^{10}$	$6,5^{10}$	$6,1^{10}$	$6,2^{10}$	$5,9^{10}$	$5,8^{10}$	$5,3^{10}$	$0,7^{10}$	0,3	0	0,4	$0,9^{10}$	$1,0^{12}$
L	$14,7^{10}$	$6,7^{10}$	$6,9^{10}$	$6,5^{10}$	$6,6^{10}$	$6,3^{10}$	$6,2^{10}$	$5,7^{10}$	$1,1^{10}$	0,7	0,4	0	0,7	0,6
M	$14,6^{10}$	$6,6^{10}$	$6,8^{10}$	$6,4^{10}$	$6,5^{10}$	$6,2^{10}$	$6,1^{10}$	$5,6^{10}$	$1,0^{10}$	0,6	$0,9^{10}$	0,7	0	1,2
N	$15,3^{12}$	$7,3^{12}$	$7,5^{12}$	$7,1^{12}$	$7,2^{12}$	$6,9^{12}$	$6,8^{12}$	$6,3^{12}$	$1,7^{12}$	$1,3^{12}$	$1,0^{12}$	0,6	1,2	0

From Table 3, we can determine the shortest path from vertex A to vertex N. In our case the shortest path leads through the vertices A - B - D - G - H - I - J - L – N and its size is 15, 3 km.

3. Optimization of Transport Routes

The second step is calculating with the Clark-Wright method. With this method we accomplish optimization of drinking water transport routes. The method is suitable to determine the optimal amount of water to be delivered to individual distribution places. At the same time, it can be used to find the shortest possible transport route of the required amount of water, from the starting point A to the designated vertices i.e. in our case, the dispensing B to N, with respect to the distances between the individual vertices and with the capacity of the means of transport. We have listed the shortest possible shipping route as follows.

The baseline solution of Table 2 is the T route, which passes through all the connections between the vertices:

$$\begin{aligned} &u_0 - u_1 - u_0 - u_2 - u_0 - u_3 - u_0 - u_4 - u_0 - u_5 - u_0 - u_6 - u_0 - u_7 - u_0 - u_8 - u_0 - u_9 - u_0 - u_{10} - u_0 - u_{11} - \\ &- u_0 - u_{12} - u_0 - u_{13} - u_0 . \end{aligned} \tag{2}$$

In our case, this is a route:

$$\begin{aligned} &T = A - B - A - C - A - D - A - E - A - F - A - G - A - H - A - I - A - J - A - K - A - L - A - M - \\ &- A - N - A = 2 \cdot (8{,}0 + 8{,}3 + 8{,}2 + 8{,}4 + 8{,}9 + 8{,}5 + 9{,}0 + 13{,}6 + 14{,}0 + 14{,}3 + 14{,}7 + 14{,}6 + 15{,}3) = 291{,}60 \text{ km.} \end{aligned} \tag{3}$$

Subsequently, from the matrix shown in Table 2, we calculated the savings matrix, using the bottom relationship (shown in Table 4). For all pairs of vertices of the B to N network, we calculated the coefficient by relationship:

$$l_{ij} = c_{i0} + c_{0j} - c_{ij}, kde\ 0 \neq 0, j \neq j, i \neq i . \tag{4}$$

Table 4

Savings matrix

	B	C	D	E	F	G	H	I	J	K	L	M	N	q_i
B	0													2500
C	16,0	0												3240
D	16,0	16,1	0											3410
E	16,0	16,3	16,4	0										2560
F	16,0	16,2	16,4	16,7	0									1600
G	16,0	16,1	16,4	16,5	17,0	0								1400
H	16,0	16,1	16,4	16,5	17,3	17,0	0							51670
I	16,0	16,1	16,4	16,5	17,3	17,0	18,0	0						3960
J	16,0	16,1	16,4	16,5	17,3	17,0	18,0	27,2	0					4970
K	16,0	16,1	16,4	16,5	17,3	17,0	18,0	27,2	28,0	0				3550
L	16,0	16,1	16,4	16,5	17,3	17,0	18,0	27,2	28,0	28,6	0			4250
M	16,0	16,1	16,4	16,5	17,3	17,0	18,0	27,2	28,0	28,0	28,6	0		4660
N	16,0	16,1	16,4	16,5	17,3	17,0	18,0	27,2	28,0	28,6	29,4	28,7	0	102000

The procedure of the method consists in determining the highest positive value l_{ij} (in case if the number already don't exists, the calculation is closed and remains the concrete route). In case, if applies inequality $Q(F_i) + Q(F_j) \leq K$ (the sum of the requirements for a particular route is not greater than or equal to the storage capacity), give for $l_{ij} = 0$ and we merge appropriate the two rides. The number new drive r we assign as $min\ \{F_i, F_j\}$. Next we choose $Q_r = Q(F_i) + Q(F_j)$ and for all vertices k from the interconnected rides $F_k = r$. If after vertices joining u_i and u_j at least one of them will no longer be linked to the centres u_0, we select all values $l_{rs} = 0$, where to either r, or s equal to the number of such a vertex. Also, the coefficients will be equal to zero l_{rs}, where vertices u_r and u_s belong to the newly established road. We repeat this process until we set to zero the entire savings matrix [4]. The result of these adjustments is the shortest transport route T_{min}, which has value in the case in question $L_{min} = 97{,}8\ km$.

It is further evident from Fig. 2 that optimal drinking water supply must be carried out in 8 circuits. Vehicles will transport potable water as part of the emergency supply of the population from the place of filling to the distribution and return along the routes:

- *A-B-C-A* (marked in blue), where it is necessary to transport 5 740 litters of water in 1 circuit;
- *A-D-E-F-G-I-J-K-L-M-A* (marked in green), where it is necessary to transport 30 360 litters of water in 1 circuit;
- *A-N-A* (marked in orange – the shortest route to the summit of N), where it is necessary to transport 102 000 litters of water in 4 circuits;
- *A-H-A* (marked in purple), where it is necessary to transport 51 670 litters of water in 2 circuits.

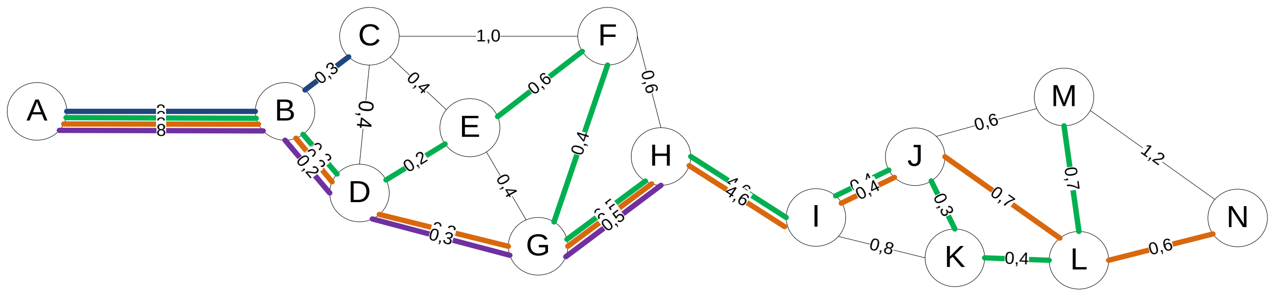


Fig. 2 Graphic representation of circuits with optimal water supply

In order to clarify which vehicles will be used specifically for the individual distribution places, the authors used the calculation using a transport task (Table 5). Vehicles are labelled:

1. 1 m^3 – drinking water tank (trailer push-cart);
2. 1 m^3 – drinking water tank (trailer push-cart);
3. 3 m^3 – drinking water tank MK 3;
4. 3 m^3 – drinking water tank MK 3;
5. 7 m^3 – car tanker MILCOM 070;
6. 7 m^3 – car tanker MILCOM 070;
7. 11 m^3 – tanker car CAV – 11.

Table 5

Solving a traffic problem with the capacity of available tanks

Distribution place of drinking water	Distance from the filling point to the distribution place of the drinking water [km]							Required quantity of drinking water [l]
	Tank							
	1	2	3	4	5	6	7	
B.	**1 000** ^{8}	**1 000** ^{8}	**500** ^{8}					2 500
C.			**2 500** ^{8,3}	**740** ^{8,3}				3 240
D.				**2 260** ^{8,2}	**1 150** ^{8,2}			3 410
E.					**2 560** ^{8,7}			2 560
F.					**1 600** ^{9,1}			1 600
G.					**1 400** ^{8,8}			1 400
H.					**290** ^{9,1}	**7 000** ^{9,1}	**11 000** ^{9,1}**; -33 380**	51 670
	1 000 ^{9,1}	**1 000** ^{9,1}	**3 000** ^{9,1}	**3 000** ^{9,1}	**7 000** ^{9,1}	**7 000** ^{9,1}	**11 000** ^{9,1}**; -380**	
	380 ^{9,1}							
I.	**620** ^{12,8}	**1 000** ^{12,8}	**2 340** ^{12,8}					3 960
J.			**660** ^{13,2}	**3 000** ^{13,2}	**1 310** ^{13,2}			4 970
K.					**3 550** ^{13,6}			3 550
L.					**2 140** ^{13,9}	**2 110** ^{13,9}		4 250
M.						**4 660** ^{13,9}		4 660
N.						**230** ^{14,5}	**11 000** ^{14,5}**; - 90 770**	102 000
	1 000 ^{14,5}	**1 000** ^{14,5}	**3 000** ^{14,5}	**3 000** ^{14,5}	**7 000** ^{14,5}	**7 000** ^{14,5}	**11 000** ^{14,5}	
	1 000 ^{14,5}	**1 000** ^{14,5}	**3 000** ^{14,5}	**3 000** ^{14,5}	**7 000** ^{14,5}	**7 000** ^{14,5}	**11 000** ^{14,5}	
	1 000 ^{14,5}	**1 000** ^{14,5}	**3 000** ^{14,5}	**3 000** ^{14,5}	**7 000** ^{14,5}	**7 000** ^{14,5}	**2 770** ^{14,5}	
Amount of drinking water in the tank [l]	1000 l	1000 l	3000 l	3000 l	7000 l	7000 l	11000 l	33 000 /189 770

Table 5 shows that the distribution place will be supplied with drinking water by tankers as follows:

- Distribution place B will to operated 3 vehicles - 1, 2, 3, which will ship 2 500 litters of water;
- Distribution place C will to operated 2 vehicles - 3, 4, which will ship 3 240 litters of water;
- Distribution place D will to operated 2 vehicles - 4, 5, which will ship 3 410 litters of water;
- Distribution places E, F and G will to operated 1 vehicle - 5, which will ship 5 560 litters of water;
- Distribution places H will to operate all vehicles - 1,5,6,7 – 2 times a 2,3,4 – 1 - times, which will ship 51 670 litters of water;
- Distribution place I will to operated 3 vehicles - 1, 2, 3, which will ship 3 960 litters of water;
- Distribution place J will to operated 3 vehicles - 3, 4, 5, which will ship 4 970 litters of water;
- Distribution place K will to operated 1 vehicle - 5, which will ship 3 550 litters of water;
- Distribution place L will to operated 2 vehicles - 5, 6, which will ship 4 250 litters of water;
- Distribution place M will to operated 1 vehicle - 6, which will ship 4 660 litters of water;
- Distribution places N will to operate all vehicles - 1, 2, 3, 4, 5 – 3 times a 6, 7 – 4 - times, which will ship 102 000 litters of water.

4. Conclusions

In order to find the optimal route for the transport of drinking water in the emergency supply of drinking water by means of tanks, we have chosen the Clark-Wright method, which has not yet been used in practice. To calculate the shortest distances, we applied the Floyd algorithm, and we used the transport task to calculate the specific tanks that will deliver to distribution place. Taking advantage of our proposal for an emergency supply of drinking water by tanks would be helpful, if the original drinking water supply could be disturbed. Thanks to this information, the crisis management authorities as well as the municipalities could plan an optimal route for the transport of drinking water to individual municipalities if disruptions to drinking water supply.

Acknowledgment

This work was supported by Project VEGA No.1/0240/15 Process model of safety and protection of critical infrastructure in the transport sector.

References

1. **Tomek, M.; Strohmandl, J.; Mihoková Jakubčeková, J.** 2017. Ochrana obyvateľstva - plánovanie a zabezpečenie evakuácie. In: The science for population protection [elektronický zdroj]. ISSN 1803-635X. Vol. 9, no. 1 [online cit.: 2018-05-01]. Available from: http://www.population-protection.eu/prilohy/casopis/33/280.pdf (in Slovak)
2. Vyhláška MŽP SR č. 220/2012, ktorou sa ustanovujú podrobnosti o zásobovaní vodou na obdobie krízovej situácie
3. **Holubčíková, D.** 2018. Optimalizácia systému zásobovania vodou počas mimoriadnej udalosti (Diplomová práca). Žilina: Katedra technických vied a informatiky, Fakulty bezpečnostného inžinierstva Žilinskej univerzity v Žiline, 151 s.
4. **Mihoková Jakubčeková, J.; Tomek, M.** 2017. Optimalizácia trasy prepravy pitnej vody pri núdzovom zásobovaní do miest ubytovania = Optimalization of the drinking water transport route at emegency supplies to the place of accommodation. In: The science for population protection. ISSN 1803-635X. Vol. 9, no. 2. [online cit.: 2018-05-01]. Available from: http://www.population-protection.eu/prilohy/casopis/35/292.pdf (in Slovak)

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Selected Aspects of the Choice Preference Assessments of the Methods of People Movements Carried out in Cities

M. Dębowska-Mróz[1], E. Ferensztajn-Galardos[2], R. Krajewska[3], A. Rogowski[4]

[1]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: m.mroz@uthrad.pl*
[2]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: e.ferensztajn@uthrad.pl*
[3]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: r.krajewska@uthrad.pl*
[4]*Faculty of Transport and Electrical Engineering, Kazimierz Pulaski University of Technology and Humanities in Radom, 29 Malczewski Street, 26-600 Radom, Poland, E-mail: a.rogowski@uthrad.pl*

Abstract

In recent years, a significant increase in the number of displacements has been observed in cities. Understanding the features of these displacements and the accompanying regularities and the division in terms of structures: motivational, temporal and generic, which determine the choice of the manner of displacement implementation, is an important task for entities dealing with modeling transport systems in cities. Based on this knowledge, important decisions are made regarding the planning and operation of the transport system in a selected area of the city, taking into account not only economic and ecological requirements, but also, and perhaps above all, preferences and needs of residents. The results of research on the preferences of the choice of means of transport by city residents on the example of Radom will be presented in this article.
KEY WORDS: *transport, city, preferences, displacements, transport relations, means of transport*

1. Introduction

Polish cities have been struggling with huge transport problems for many years. This mainly applies to large and medium cities. The cause of these problems is the rapid increase in the number of vehicles and mobility of people, and repeatedly the lack of a reasonable policy for the development of the road transport system and underinvestment of tasks related to road infrastructure [2]. Excessive congestion and problems with maintaining the flow of traffic cause more and more obstacles for all road users. Increasing losses of time and increasing threats related to traffic safety in these areas are a consequence of this situation [7].

Planning transport accessibility and its most important technical and organizational elements in cities is one of the elements of transport policy [8]. Understanding the specificity of displacements performed in a given space and the accompanying regularities is another task. Their division in terms of motivational, temporal and generic structures, which determine the choice of the method of displacement implementation, is a significant problem in the field of traffic modeling in cities, which are dealt with by entities responsible for the functioning of transport systems [2]. Significant decisions regarding the planning and operation of the transport system in a selected area of the city or in the whole city, taking into account the diverse needs of various participants of the transport space, are made on the basis of such knowledge [4]. Decisions regarding the construction and modernization of the transport system taking into account not only economic and ecological requirements, but also, and perhaps first and foremost, the preferences and needs of residents are made on the basis of the analyzes carried out.

2. Assessing the Preferences of City Residents Associated with the Choice of Methods of Transport Displacement

Preferences of urban transport passengers can be seen as human expectations related to the quality of transport services [5, 6]. Detailed requirements on how to meet transport needs in cities are referred to as transport postulates, which can be differentiated and their number is constantly changing [3]. Their specificity is influenced by such factors as: current experience, transport conditions, the automotive status of the traveler, the level and lifestyle in cities (Table 1).

In order to identify the importance of individual factors on the functioning of the transport system in Radom, pilot surveys were carried out. The research co-ordinators were students of the Faculty of Transport and Electrical Engineering UTHRad: M. Szajnowicz and A. Wieczorek, who collected data for the preparation of their diploma theses. The study included 400 people. Obtained results relevant from the point of view of the issues discussed in this study are presented in Table 2 and Figs. 1-6.

The choice of means of transport (Table 2) does not depend on the means of transport held, because over 60% of respondents have a car at their disposal and over 20% have a working bicycle. It is worth noting that in Radom operates a city bike system from 2017. The displacements are carried out for professional and educational purposes (Table 2).

Respondents choosing the method of displacements most often pay attention to the cost (19.86%), availability (12.7%) and weather (9.86%) (Fig. 1).

Table 1

Interpretation of transport postulates for urban transport

Postulate	importance of the postulate
Directness	connection without having to change
Frequency	intervals between departures of vehicles of the same line
Availability	distance to the bus stop (spatial or temporary)
Information	the way of providing information about the transport offer and changes in the offer
Cost	one-off or periodic tariff payment
Certainty	getting to destination on time driving
Speed	time including stopping on the route
Punctuality	compatibility of departures with the timetable
Rhythmicity	uniform intervals of time between departures in the same direction
Convenience	a set of elements determining the waiting conditions at the bus stop and staying in the vehicle

Source: [9, s. 25].

Table 2

Access to different means of transport and reasons for displacements

The manner of realized displacements	Having a transportable means of transport				Destinations of displacements carried out by respondents						
	car	bicycle	moped	motorcycle	education	work	shoppings	doctor's appointment	visits (family, friends)	recreation	Other purposes
on foot every day	63.58%	20.37%	9.88%	6.17%	33.33%	31.48%	12.96%	0.62%	9.88%	4.94%	6.79%
on foot once, 2-3 times a week	55.43%	17.39%	7.61%	19.57%	25.54%	39.13%	20.11%	0.54%	5.98%	4.89%	3.80%
on foot less	48.10%	13.92%	8.86%	29.11%	7.59%	51.90%	11.39%	0.00%	11.39%	10.13%	7.59%
by bicycle every day	36.00%	20.00%	16.00%	28.00%	0.00%	50.00%	23.08%	0.00%	11.54%	7.69%	7.69%
by bicycle once, 2-3 times a week	47.83%	17.39%	8.70%	26.09%	14.89%	46.81%	13.83%	0.00%	9.57%	8.51%	6.38%
bike less	58.30%	16.96%	9.19%	15.55%	21.13%	40.49%	19.01%	0.35%	7.04%	7.39%	4.58%
by car every day	55.72%	18.41%	7.46%	18.41%	23.38%	39.30%	20.90%	0.50%	6.47%	5.47%	3.98%
by car once, 2-3 times a week	52.38%	19.05%	6.80%	21.77%	23.13%	39.46%	21.09%	0.68%	6.12%	5.44%	4.08%
by car rarely	46.03%	17.46%	9.52%	26.98%	1.59%	53.97%	14.29%	0.00%	11.11%	11.11%	7.94%

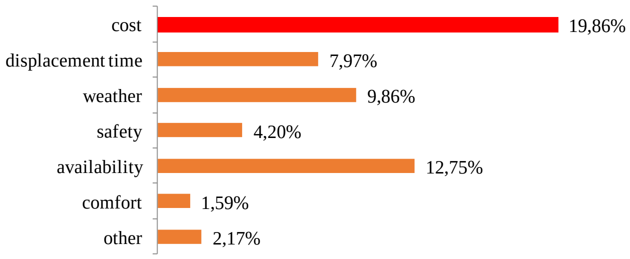


Fig. 1 Factors deciding about the choice of the displacement method

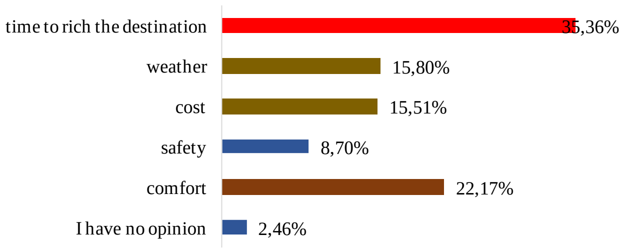


Fig. 2 Factors determining the choice of the means of transport for the movements carried out

The factors influencing decisions made by respondents on the methods of displacement carried out (Fig. 2) are the time to reach the destination (35.36%), comfort (22.1%) and the weather (15.8%).

Differentiation of assessments depending on the method of displacements carried out is presented in Figure 3.

The standard of the communication route is important for people carrying out movements on foot (24.5%) and by car (39.16%). In the case of people who perform bicycle movements, the biggest problem is the lack of proper lighting of routes dedicated to cyclists (Fig. 3). This is also important from the point of view of the safety of those road users.

It is also worth paying attention to the aspects of accessibility to selected elements of point infrastructure by planning a transport system in cities. In the case of collective transport, this is a very important factor determining the perception of the entire collective transport service system (Figs. 4, 5). Respondents also pay attention to the lighting of stops and the location of pedestrian crossings in their vicinity (Fig. 4).

Taking various decisions regarding planned changes in the functioning of the transport system in cities, it is worth paying attention to the factor that may be significant in the event of any decision on changing the current mode of transport (Fig. 6).

Planning of the transport system in cities covers diverse groups of issues, which focus mainly on ensuring the implementation of efficient, fast, safe and environmentally friendly displacements that take into account different groups of displacements.

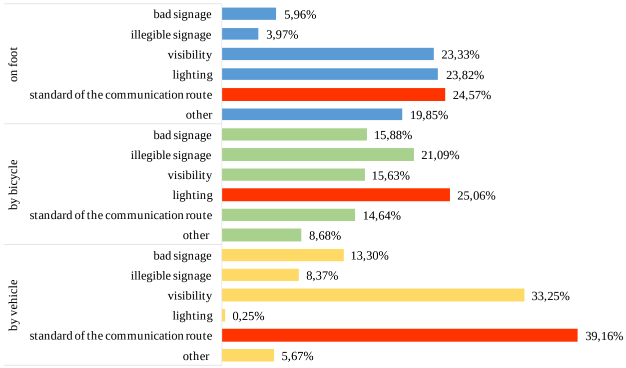


Fig. 3 Summary of assessments related to transport infrastructure depending on the manner of displacements

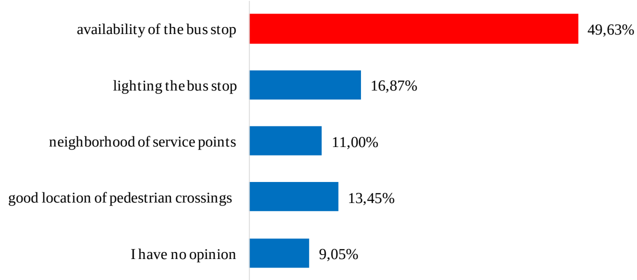


Fig. 4 Summary of the most important factors regarding the assessment of spatial accessibility to public transport stops

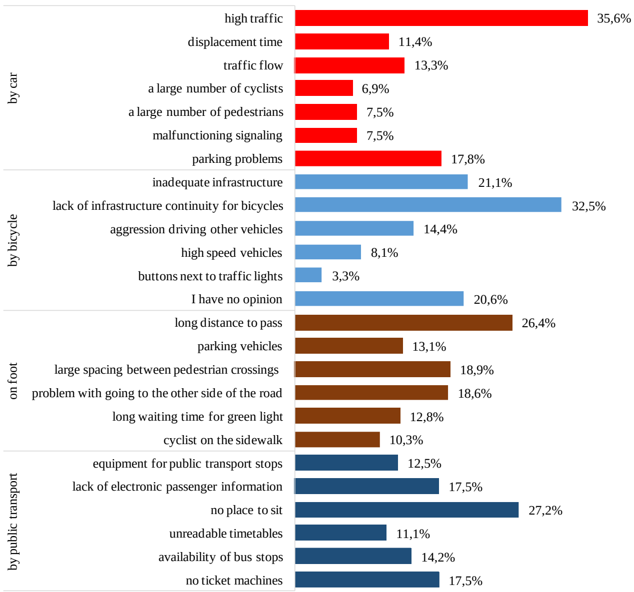


Fig. 5 Summary of factors perceived as barriers by respondents in different ways of carrying out displacements

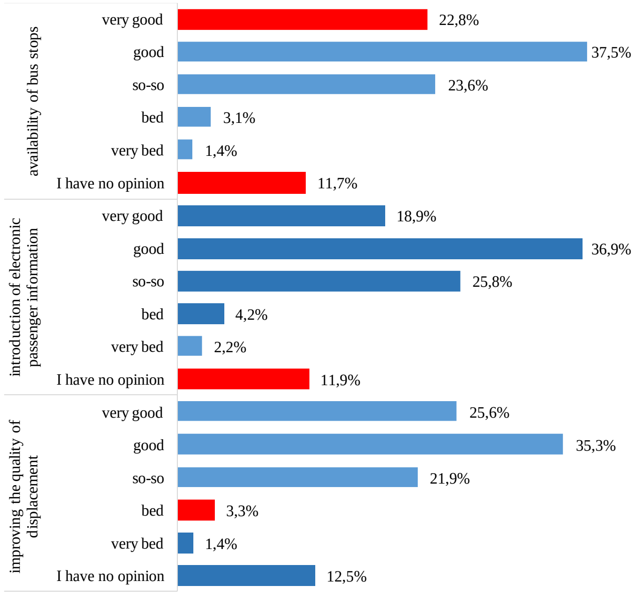


Fig. 6 Summary of factors that may have an impact on the greater use of public transport to carry out everyday displacements

3. Analysis of Methods of Carrying out Displacements of City Residents

When analyzing the choice of methods of moving city residents, it is also important to determine what percentage of displacements is carried out by more than one means of transport (combined trips), what displacements of source-destination are thus realized, what percentage of displacements made by a given means of transport are combined trips, groups of inhabitants carry out such movements. In the case of Radom residents, partial answers to these questions are given in Tables 3 and 4. The dominant role is played by trips involving pedestrians (nearly 95% of all combined trips) and urban transport (over 86% of combined trips), with trips from using pedestrian displacements and public transport simultaneously account for 80.11% of combined trips (Table 4). Relatively much (in absolute numbers) there are movements on foot + passenger car as a driver (7.11% of combined trips), movements on foot + passenger car as passenger (4.87% of combined trips) and public transport + passenger car as passenger (3.69%). Other means of transport and other connections with the participation of pedestrian and public transport are of marginal importance from the point of view of participation in combined trips. Determining the share of trips combined with the use of a given means of transport in combined trips and total number of trips is insufficient, the share of combined trips in displacements carried out with a given means of transport is also important (Table 4). Over 30% of them are displacements on foot, by public transport, by private bus transport (buses) and by rail. The last two ways of relocation do not have a significant share in combined journeys (1.84% and 1.32% respectively, Table 3.) as well as total number of trips (0.48%

and 0.24% respectively, Table 4.). However, at this point we should ask how respondents moved to the railway station to travel by rail, since in 2/3 travel by rail they did not indicate another means of travel (they were not combined trips). In the case of "other means of transport", the share of combined trips is 11.26%, and the passenger car as passenger is 8.09%. In the case of displacement by car, which account for over 44% of total trip, combined trips represent a small part - 1.83% (Table 4), but due to the number of trips made in this way it is close to 10% of combined trips. Please note that car displacement represents 53.85% of total movements (1.53% is combined trips, a curiosity is the fact that there are trips in which moving resident is both a driver and a passenger). It should be noted that in the case of residents of ROF communes (9 rural and rural-urban communes were surveyed, entering, apart from Radom, as part of the Radom Functional Area), the share of combined trip is definitely different than in the case of Radom residents. We leave the analysis of the differences to the Reader - the necessary data for the analysis can be found in Tables 6 and 7.

We try to answer the question, for what purpose (source - destination) and what groups of residents used combined trips. We will limit ourselves to displacements on foot and public transport.

Table 3

Displacements made by respondents of the inhabitants of Radom using at least two means of transport (combined trips)

Number of displacements (combined trips) using means of transport (x, y)											**Participation in total trips**	**Participation in combined trips**
x \ y	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**		
1	x	54	37	608	10	2	0	7	2	720	8.82%	94.86%
2	54	x	6	8	0	0	0	4	0	72	0.88%	9.49%
3	37	6	x	28	0	2	0	2	0	75	0.92%	9.88%
4	608	8	28	x	4	6	0	3	0	657	8.05%	86.56%
5	10	0	0	4	x	0	0	0	0	14	0.17%	1.84%
6	2	0	2	6	0	x	0	0	0	10	0.12%	1.32%
7	0	0	0	0	0	0	x	0	0	0	0.00%	0.00%
8	7	4	2	3	0	0	0	x	0	16	0.20%	2.11%
9	2	0	0	0	0	0	0	0	x	2	0.02%	0.26%
Number of displacements using at least two means of transport										**759**	**9.30%**	
Total number of displacements										**8161**		

Note: Some displacements are carried out using more than one means of transport. 1 – on foot; 2 – a car - as a driver; 3 – a passenger car - as a passenger; 4 – public transport bus; 5 – bus, private bus; 6 – railway; 7 – Taxi; 8 – bicycle; 9 – other means

Source: own materials based on [1].

Table 4

Estimated average daily number of movements of the inhabitants of Radom using a given means of transport using one and many means of transport and participation in total trips

	Means of transport								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
The percentage of Radom residents using the given means of transport [%]	32.330	46.200	13.740	28.440	0.340	0.720	0.580	3.880	0.340
The average daily number of transports by means of a given means of transport carried out by a resident of Radom	0.770	1.230	0.270	0.652	0.013	0.007	0.008	0.086	0.006
The average daily number of combined trips made by a resident of Radom using the given means of transport	0.242	0.022	0.022	0.223	0.005	0.002	0.000	0.005	0.001
Estimated daily number of displacements carried out by inhabitants of Radom using the given means of transport	143972	230059	50415	121966	2521	1274	1525	16115	1111
Share of combined trips in transfers using the given means of transport [%]	31.450	1.830	8.090	34.210	33.610	36.340	0.000	5.390	11.260
The share of the displacements using the given means of transport in total trips [%]	27.680	44.230	9.690	23.450	0.480	0.240	0.290	3.100	0.210
The share of combined trips with the use of a given means of transport in total trips [%]	8.700	0.810	0.780	8.020	0.160	0.090	0.000	0.170	0.020
The share of displacements not included with the use of a given means of transport in total trips [%]	18.970	43.420	8.910	15.430	0.320	0.160	0.290	2.930	0.190
The number of "implemented" motivations using the given means of transport	47	55	37	44	12	9	11	24	11
The average daily number of displacements carried out by a resident of Radom in total								**2.782**	
The daily number of displacements carried out by the inhabitants of Radom in total								**520200**	

Source: own materials based on [1]

a. Combined trips: displacements on foot + public transport

In all age groups (Table 5), the average daily number of combined displacement on foot + public transport performed by women is significantly higher than that of men - especially large differences occur in the age groups of 45 59 and over 60 years. Even greater differences occur in the number of source-destination motivations carried out (in wom-

en, these numbers are much larger). 8 sources/destinations motivations have been defined[1] , which gives a total of 64 possible motivations. The following shares have the largest share in particular age groups:

– 13-17 years: women 1-3 (28.6%), 3-1 (21.4%), 1-5 (14.3%), 1-8 (14.3%); men: 1-3 (33.3%), 3-1 (33.3%), 1-5 (16.7%), 5-1 (16.7%);

– 18-44 years: women - 1-2 (21.1%), 2-1 (17.8%), 1-3 (7.9%), 1-8 (7.9%), each 8 sources/destinations; men - 1-2 (12.9%), 5-1 (12.9%), 1-3 (11.9%), 8-1 (11.9%), 2-1 (10.9%)), there is no 6 motivation as a source or destination;

– 45-59 years: women - 1-2 (17.1%), 2-1 (14.0%), 8-1 (9.3%) and 1-7, 1-8, 4-1, 7 -1 (after 7.8%), there is no 3 as a source of displacement; men - 1-2 (17.1%), 2-1 (14.3%), 7-1 (14.3%), there are only relationships where 1 is the source or destination of the trip, there are no 3 and 6 motivation;

– over 60 years: women - 1-8 (18.4%), 8-1 (18.4%), 4.1 (14.0%), 1-7 (13.2%), 1-4 (12.3%), 7-1 (10.5%), there are only relationships where 1 is the source or destination of the trip, there are no 3 and 6; men - 1-8 (17.6%), 8-1 (13.7), 1-7 (13.7%), 7-1 (11.8%), 1-4 (9.8%), there is no 3 motivation as a source or destination.

Table 5

Daily number and average number of displacements and number of implemented source-destination motivations of Radom residents in particular age groups, including gender

7.50%	**Combined trips: displacements on foot + public transport**														
Gender	**Women**					**Men**					**Women + Men**				
Age	**13-17**	**18-44**	**45-59**	**60+**	**Total**	**13-17**	**18-44**	**45-59**	**60+**	**Total**	**13-17**	**18-44**	**45-59**	**60+**	**Total**
A	0.219	0.199	0.329	0.275	0.254	0.171	0.150	0.129	0.194	0.157	0.194	0.174	0.237	0.244	0.209
B	1058	8087	7600	8633	25378	875	6316	2540	3892	13624	1933	14403	10140	12525	39001
C	7	19	22	13	29	4	15	10	14	19	7	22	22	16	33
0.66%	**Combined trips: displacements on foot + passenger car as a driver**														
A	0.000	0.018	0.018	0.005	0.013	0.000	0.019	0.048	0.019	0.025	0.000	0.019	0.032	0.010	0.018
B	0	745	412	151	1309	0	813	944	382	2138	0	1558	1356	533	3447
C	0	8	4	2	10	0	4	4	5	9	0	10	6	5	14
0.44%	**Combined trips: displacements on foot + passenger car as passanger**														
A	0.031	0.021	0.020	0.014	0.019	0.000	0.003	0.007	0.004	0.004	0.015	0.012	0.014	0.010	0.012
B	151	851	471	454	1928	0	125	145	76	347	151	976	616	531	2275
C	2	5	5	4	10	0	2	2	1	5	2	6	5	5	12
0.36%	**Combined trips: car communication + passenger car as passenger**														
A	0.031	0.010	0.003	0.022	0.013	0.057	0.006	0.000	0.000	0.006	0.045	0.008	0.001	0.013	0.010
B	151	426	59	682	1317	292	250	0	0	542	443	676	59	682	1859
C	2	7	1	5	11	2	4	0	0	6	4	9	1	5	12

Note: The share of combined trips using the indicated means of transport in the total number of trips is given in the cells of the table marked in yellow.

A - average daily number of displacements [number of trips / person], B - estimated daily number of displacements, C - number of realized source-destination motivations.

Source: own material based on [1].

Table 6

Displacements carried out by respondents from the ROF municipalities using at least two means of transport (combined trips)

Number of displacements (combined trips) using means of transport (x, y)											**Participa-tion in total trips**	**Participa-tion in com-bined trips**
x \ y	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**		
1	x	66	28	41	43	10	0	15	0	203	8.28%	56.55%
2	66	x	36	19	14	4	0	5	2	146	5.95%	40.67%
3	28	36	x	30	13	4	0	2	0	113	4.61%	31.48%
4	41	19	30	x	51	6	0	16	2	165	6.73%	45.96%
5	43	14	13	51	x	2	0	4	1	128	5.22%	35.65%
6	10	4	4	6	2	x	0	0	0	26	1.06%	7.24%
7	0	0	0	0	0	0	x	0	0	0	0.00%	0.00%
8	15	5	2	16	4	0	0	x	2	44	1.79%	12.26%
9	0	2	0	2	1	0	0	2	x	7	0.29%	1.95%
Number of displacements using at least two means of transport										**359**	**14.64%**	
Total number of displacements										**2452**		

Note: Some displacements are made using more than one means of transport. 1, 2, ..., 9 as in Table 2

Source: own materials based on [1].

[1] Eight source/destination motivations were distinguished: 1 – House: place of residence; 2 – Work: place of starting work; 3 – Education: schools, colleges, place of course, training; 4 –Shopping and services: to the kiosk, shop, shopping center; 5 – Recreation and entertainment: for sports, cinema and restaurants; 6 – Business matters: all trips made as part of work; 7 – Offices, hospitals, clinics, banks, courts: performed not as part of work; 8 – Other purposes: eg travel for a person, delivery of a person.

Table 7

Estimated average daily number of displacements of inhabitants of ROF communes by means of transport using one and many means of transport and participation in total trips

	Means of transport								
	1	2	3	4	5	6	7	8	9
The percentage of residents of ROF communes using the given means of transport [%]	19.96	43.87	18.03	14.39	12.46	2.43	0.30	9.63	0.51
The average daily number of transports by means of a given means of transport carried out by a resident of ROF communes	0.383	1.148	0.386	0.379	0.278	0.045	0.005	0.220	0.011
The average daily number of combined trips made by a resident of ROF communes using the given means of transport	0.198	0.128	0.109	0.153	0.118	0.022	0.000	0.050	0.005
Estimated daily number of displacements carried out by inhabitants of ROF communes using the given means of transport	38454	115325	38737	38109	27948	4505	496	22087	1088
Share of combined trips in transfers using the given means of transport [%]	51.63	11.13	28.38	40.27	42.41	49.15	0.00	22.55	44.53
The share of the displacements using the given means of transport in total trips [%]	14.96	44.86	15.07	23.45	10.87	1.75	0.19	8.59	0.42
The share of combined trips with the use of a given means of transport in total trips [%]	7.72	4.99	4.28	8.02	4.61	0.86	0.00	1.94	0.19
The share of displacements not included with the use of a given means of transport in total trips [%]	7.23	39.87	10.79	15.43	6.26	0.89	0.19	6.65	0.23
The number of "implemented" motivations using the given means of transport	24	55	32	44	25	13	5	16	7
The average daily number of displacements carried out by a resident of ROF communes in total								**2.560**	
The daily number of displacements carried out by the inhabitants of ROF communes in total								**257400**	

Source: own materials based on [1].

b. Combined trips: displacements on foot + passenger car as a driver

In this case, in the age group 45-59 and over 60 men on average carry out more trips a day than women, in other groups it can be concluded that there are no differences between women and men. We can notice, what seems natural, that such trips do not occur in the 13-17 age group. The following relationships participate in particular age groups:

– 18-44 years: women - 1-8 (28.57%), 1-2 (21.43%), 2-1 (14.29%) and 1-4, 2-3, 3-8, 4 -1.8-1 (7.14% each); men: 1-2 (38.46%), 2-1 (38.46%), 1-3 (15. 15%), 3-1 (7.69%);

– 45-59 years: women - 2-1 (42.86%), 1-2 (28.56%), 1-7 (14.29%), 7-1 (14, 29%); men - 1-2 (46.15%), 2-1 (38.46%), 7-6 (7.69%), 8-1 (7.69%);

– over 60 years: women - 4-1 (50%), 1-4 (50%); men - 1-2, 1-4, 2-1, 4-1, 8-4 (20% each).

c. Combined trips: displacements on foot + passenger car as passenger

Women, in all age groups perform more displacements than men, they also realize more relationships. The following relationships participate in particular age groups:

– 13-17 years: women - 1-3 and 3-1 (50% each); men: no displacements,

– 18-44 years: women - 1-2, 2-1, 4-1 (25% each), 1-4, 1-8 after (12.5%); men - 1-8, 8-1 (50% each);

– 45-59 years: women - 1-2, 1-4, 1-7 (25% each) and 2-1, 4-5 (15% each); men - 1-2, 2-1 (50% each);

– over 60 years: women - 1-4, 4-1 (after 33.33%) and 1-7, 4-4 (!) (16.67% each); men - only 1-5.

d. Combined trips: public transport + passenger car as passenger

The situation is similar to that of case 4 with the exception of the 13-17 age group in which men perform more displacement. The following relationships participate in particular age groups:

– 13-17 years: women - 1-4 and 4-1 (50% each); men: 1-3 and 3-1 (50% each);

– 18-44 years: women - 1-8 (25%) and 1-2, 1-3, 2-1, 3-1, 8-1, 8-2 (12.5% each); men - 1-4, 1-8, 4-4, 8-1 (25% each);

– 45-59 years: women - only 1-4; men - no displacement;

– over 60 years: women - 1-7 (44.44%, 7-1 (22.22% each) and 1-4, 1-8, 8-1 (11.11% each) men - no displacement.

However, it should be noted that in cases b, c, d, due to the low percentage of respondents doing such combined trips, we should be very careful about the identified motivations (relations) source - destination.

4. Conclusions

The implementation of everyday displacements in cities is one of the most important determinants specifying the quality of human functioning in these spaces. It is not enough just transport infrastructure and provided on the basis of its transport service. It is also necessary to attach the need to respect the principle of sustainable development and the right to mobility as a universal transport service for the acceptance of displacements in line with the growing expectations of speed and access to information. The challenges posed to the organizers of the transport space require synchro-

nization with spatial planning, architecture (especially urban), environmental protection, traffic safety and public safety, work time organization, production and supply organization. Identification of methods of displacement implementation and determination of preferences with this relocation should be seen as an important element of shaping the transport offer. Appropriate monitoring of acquired knowledge and possible changes should be done systematically. Such an approach to solving these problems may contribute to the proper shaping of transport systems in cities.

References

1. **Ciszewski, T.; Dębowska-Mróz, M.; Ferensztajn-Galardos, E.; Grad, B.; Krajewska, R.; Łukasik, Z.; Rogowski, A.; Wojciechowski, W.** 2014. Analiza przemieszczeń i preferencji komunikacyjnych na obszarze ROF opracowanie zespołu UTH Radom (umowa NR 1/KM4/2014 z dnia 21 maja 2014 r. między SITK Oddział w Krakowie a UTH w Radomiu) w ramach projektu Zintegrowane planowanie transportu zrównoważonego miejskiego Radomskiego Obszaru Funkcjonalnego (umowa MPU-II/3302/4/2014 z dnia 22.04.2014 r. między Miejską Pracownią Urbanistyczną w Radomiu a SITK Oddział w Krakowie), materiał niepublikowany (in Polish).
2. **Dębowska-Mróz, M.; Rogowski, A.** 2013. Analiza zmian natężenia ruchu drogowego na wybranych ciągach komunikacyjnych w Radomiu, Technika Transportu Szynowego – koleje, tramwaje, metro 10: 2953-2968 (in Polish).
3. **Dębowska-Mróz, M.; Zawisza, T.** 2017. Ocena napełnienia samochodów osobowych w aspekcie poprawy wykorzystania przestrzeni transportowej w miastach, Autobusy 12: 1814-1818 (in Polish).
4. **Hebel, K.** 2010. Preferencje pasażerów miejskiego transportu zbiorowego. Zeszyty Naukowe Uniwersytetu Szczecińskiego nr 603, Ekonomiczne Problemy Usług 59, Szczecin (in Polish).
5. **Mądziel, M.** 2016. Potrzeby transportowe w odniesieniu do systemów komunikacji miejskiej, Autobusy nr 12 (in Polish).
6. **Starowicz, W.** 2007. Jakość przewozów w miejskim transporcie zbiorowymi, Politechnika Krakowska (in Polish).
7. **Starowicz, W.** 2010. Ekspertyza. Koncepcja rozwoju transportu publicznego w miastach. Ministerstwo infrastruktury, Warszawa (in Polish).
8. **Szołtysek, J.** 2011. Kreowanie mobilności mieszkańców miast. Wolters Kluwer, Warszawa (in Polish).
9. **Wyszomirski, O., Grzelec, K.** 1998. Badania marketingowe w komunikacji miejskiej, Izba Gospodarcza Komunikacji Miejskiej, Warszawa (in Polish).

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Cargo Fastening on Automobile Transport Considering Its Deformation

A. O. Shimanovsky, I. E. Krakava, V. I. Yakubovich, I. A. Varazhun

Belarusian State University of Transport, Kirova 34, 246653, Gomel, Belarus, E-mail: tm.belsut@gmail.com

Abstract

The transportation safety of goods in rigid package can be ensured by calculation of the cargo fastening parameters in accordance with the current regulatory documents. However, a significant amount of the carried goods is highly deformable. There are possible both the displacement and the deformation of the cargo due to the influence of dynamic loads at the transportation process. The purpose of the presented work is to determine the conditions of the safe cargo transportation. The mechanic-mathematical models of transport packages formed from sandwich panels were developed and they considered deformations of the panels and the means of their fastening at the transportation process. Using the ANSYS complex, a finite element simulation of the stress-strain state of the bottom sandwich panel is performed for the cases of different number of similar panels placed above it. There are proposed the recommendations that allow preserving the consumer properties of the cargo after the long-term transportation.

KEY WORDS: *cargo fastening, sandwich panels, package deformations, cargo oscillations, stress-strain state, finite element modeling*

1. Introduction

The goods transported by road transport have various physical and mechanical properties. Along with the objects of a high rigidity, there are also transported the elements of constructions which can be deformed under the action of dynamic loads and forces located in the means of fastening. For example, the sandwich panels, widely used in construction, have such characteristics. This panel is a three-layer structure, which includes two covers of metal profiled sheets, and mineral wool plates of low rigidity as middle layer located between the covers [1]. For transportation, they are grouped into the transport packages consisted of several piled panels. Such a package has significant dimensions but a small mass. In order to increase the car loading the shippers place transport packages in two tiers. Therefore, the center of the transported cargo gravity is high above the vehicle floor, which can lead to the cargo stability loss, as well as to its longitudinal and transverse displacement [2]. The existing rules for the goods carriage and secure for road transport [3] and the corresponding recommendations [4] are developed for the case of the rigid type of cargo. Therefore, they can’t be commonly used especially for the situations when the transport packages are destroyed and cargo is damaged due to the deformations of fastening means, packaging material and cargo during transportation [5, 6].

The absolute majority of studies on the cargo fastening on vehicles are also devoted to the transportation safety ensuring for the bodies with the negligible deformations. So in [7] the various schemes of the cylindrical bodies fastening are investigated. In the work [8] along with the analysis of the static and dynamic stability of the fixed load, its effect on the inner surface of the container is considered. There are a number of studies devoted to the analysis of cargo fastenings on railway transport considering the deformation of the fastening means. For example, in [9] it is proved that the safety of the tubes at the train cars collision can be ensured by changing the wire straps rigidity. The effect of the transported cargo displacements on the safety of transportation has been considered in sufficient details for the case of the liquid cargo transportation [10]. There were not found investigations which take into account a complex of phenomena associated with simultaneous deformation of the cargo and the fastenings at the transportation process. The purpose of the presented work is to analyze the practical application of the existing sandwich panels packages fixing and to develop proposals to ensure the cargo safety during long transportation.

2. Dynamic Model of the Cargo Oscillations in the Transverse Plane

As it was pointed above the feature of the transported sandwich panels is the low rigidity of their middle layer. Depending on the type of the problem to solve this panel can be considered as the three-layered rod or plate, which equilibrium and oscillations are widely investigated by different authors. For example, in the articles [11, 12] the quasistatic deformation of the elastic and elastoplastic multilayer rods are investigated. In [13, 14], the stress-strain state of the located on a stationary base elastic three-layer rectangular plate with a compressible filler is considered. The monograph [15] is devoted to the dynamics of multilayer structures. However, the application of the elasticity and plasticity theories analytical methods is a fairly complex mathematical problem, even for the case of a single plate. The application of numerical methods of dynamic analysis for the case of geometrically nonlinear deformations is a very time-consuming process [16]. Therefore, there was a need to develop simplified models that describe the basic features of the sandwich panel package deformations.

To analyze the effect of the transverse inertia forces at the entrances to the turns on the transported cargo displacements, a mechanical-mathematical model has been developed. It is a model of two piled transport packages formed from the sandwich panels. Fig. 1 shows the calculation scheme of such a system. Each transport package is modeled as the two beams, interconnected by springs of *c* rigidity coefficient, simulating the deformation of mineral wool. It was assumed that the transported packages are tightly fixed and they can't slide along the body surface. In such a case, the mass of the beam 1 is half the mass of the considered package ($m_1 = m/2$), and the body 2 mass is the total mass ($m_2 = m$) of the package. Fastening of transport packages is performed with by the pressure belts *QD* and *EM*, which are under the action of the load inertial force and they take the tensile loads. To consider the transverse forces at the transport packages deformation, a damper is added into the model.

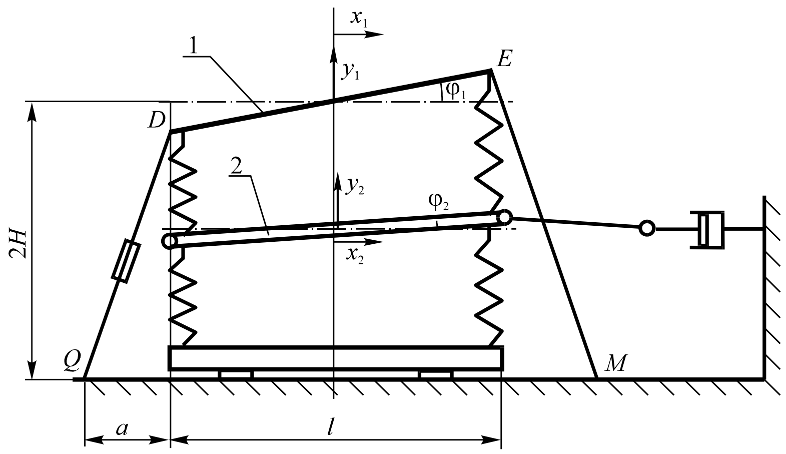


Fig. 1 The calculation scheme: *1* – the upper tier, *2* – the bottom tier

The considered system has six degrees of freedom in the case of analysis of the one plane motion. The horizontal (x_1, x_2) and vertical (y_1, y_2) displacements of the bodies 1 and 2 centers of mass, as well as the angles of their rotations (φ_1, φ_2) (Fig. 1) are taken as the generalized coordinates. Using the Lagrange's equations of the second kind, the system of differential equations was obtained and it describes system small oscillations:

$$\ddot{x}_1 = -\frac{2k}{m}\left(2(a+x_1) - \frac{\delta(a+x_1)}{\sqrt{(a+x_1)^2 + (-\varphi_1 l + y_1 + 2H)^2}} - \frac{\delta(a-x_1)}{\sqrt{(a-x_1)^2 + (\varphi_1 l + y_1 + 2H)^2}}\right);$$

$$\ddot{x}_2 = \frac{1}{m}\left[\frac{2c(x_1-x_2)(y_1-y_2)}{H+y_1-y_2} - \frac{2cx_2y_2}{H+y_2} - \alpha\dot{x}_1\right];$$

$$\ddot{y}_1 = -\frac{2}{m}\left[\frac{mg}{2} + k\left(2(\varphi_1 l + y_1) - \frac{\delta(-\varphi_1 l + y_1 + 2H)}{\sqrt{(a+x_1)^2 + (-\varphi_1 l + y_1 + 2H)^2}} - \frac{\delta(\varphi_1 l + y_1 + 2H)}{\sqrt{(a-x_1)^2 + (\varphi_1 l + y_1 + 2H)^2}}\right) + 2c(y_1 - y_2)\right];$$

$$\ddot{y}_2 = -\frac{1}{m}(mg - 2cy_1 + 4cy_2);$$

$$\ddot{\varphi}_1 = -\frac{24}{ml}\left(2cl(\varphi_1 - \varphi_2) + k\left(2l\varphi_1 + 2y_1 - \frac{\delta(-\varphi_1 l + y_1 + 2H)}{\sqrt{(a+x_1)^2 + (-\varphi_1 l + y_1 + 2H)^2}} - \frac{\delta(\varphi_1 l + y_1 + 2H)}{\sqrt{(a-x_1)^2 + (\varphi_1 l + y_1 + 2H)^2}}\right)\right);$$

$$\ddot{\varphi}_2 = -\frac{24c}{m}(\varphi_1 - 2\varphi_2),$$

here *k* – the rigidity coefficient of the fixing straps; $\delta = \sqrt{a^2 + 4H^2} - \Delta l_0$; Δl_0 – the initial strap elongation; α – the coefficient of resistance to the body displacement along the transverse direction; the point above the variable denotes differentiation with respect to time *t*.

On the base of the MathCAD software the system of the differential equations was solved for the following initial conditions: $t = 0$, $x_{10} = 0{,}001\,\text{m}$; $\dot{x}_{10} = 0$; $x_{20} = 0$; $\dot{x}_{20} = 0$; $y_{10} = -0{,}02\,\text{m}$; $\dot{y}_{10} = 0$; $y_{20} = -0{,}01\,\text{m}$; $\dot{y}_{20} = 0$; $\varphi_{10} = 0$; $\dot{\varphi}_{10} = 0$; $\varphi_{20} = 0$; $\dot{\varphi}_{20} = 0$. The initial coordinate x_{10} was taken not equal to zero to perform the analysis of the

investigated system at small perturbations. Fig. 2 shows the dependencies of the body 2 horizontal displacement and velocity on time for the following initial data: $m = 784$ kg, $a = 0{,}6$ m, $H = 0{,}96$ m, $l = 0{,}595$ m, $k = 34176$ N/m, $c = 1{,}189 \cdot 10^7$ N/m. Fig. 2 demonstrates the dependences of the displacement and velocity on the rigidity coefficient of the panel middle layer (for the upper cover $c_1 = 2c$, for the bottom cover $c_2 = 0{,}5c$).

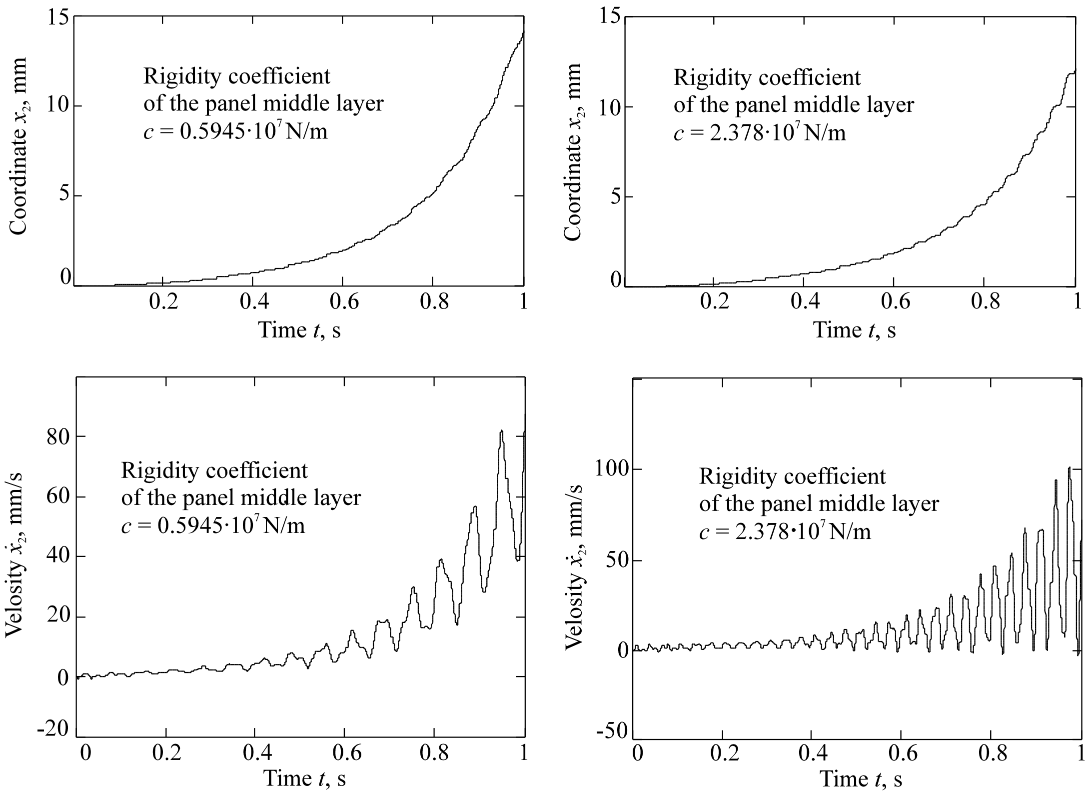


Fig. 2 The dependencies of the body 2 horizontal displacement x_2 and velocity $\dot{x}_2$ on time

The computations performed for various mechanical properties of the springs and fixing straps demonstrated that the vertical oscillations amplitude values for the bodies 1 and 2 are near 2 cm. At the same time the velocity amplitude gradually increases as well as the panel are moved along the transverse direction. Such displacement occurs, for example, at the turn entrances. The performed calculations show the transverse rigidity insufficiency for the cargo packages placed in two tiers in height. This fact leads to displacements of the panels inside the package when at the beginning and the end of the automobile movement in the turns.

3. Finite Element Modeling of the Bottom Panel Deformation

To analyze the possibility of the cargo damage due to the structure insufficient strength under dynamic loads, it was simulated the stress-strain state of the bottom panel of the pile consisting of two transport packages of 7 sandwich panels in each. Fig. 3 shows the calculation scheme for the determination of the dynamic loads and forces acting the bottom panel.

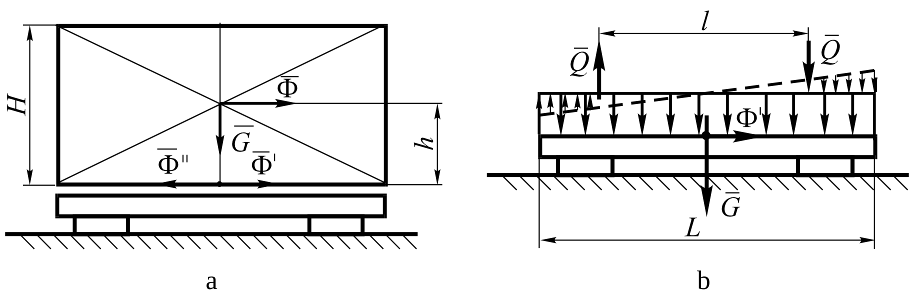


Fig. 3 The calculation schemes: a - the initial one; b - the transformed one

The action of the inertia forces $\vec{\Phi}$, applied to the upper placed panel leads to the uneven vertical pressure and it is taken into account by adding the distributed load with a linearly varied intensity. The equivalence of the initial and the transformed systems of forces is ensured by the condition:

$$\Phi \cdot h = Q \cdot 2l\,, \qquad (1)$$

where Φ – the inertia force applied to the cargo center of mass, $\Phi = m_{\Sigma} \cdot a$; m_{Σ} – the total mass of the 13 panels, it is equal to 1456 kg; a – the longitudinal acceleration equal to 0,8g, $a = 7{,}85\,\text{m/s}^2$; h – the arm of couple, h = 0,89 m; H – the height of two packages of 7 panel tiers considering the presence of foam pads of 0,04 m thickness, H = 1,78 m; L – the panel length, L = 4,13 m; l – the distance between the resultant forces from the distributed load, l = 2,065 m.

The resultant forces from the distributed load $Q = ql/2$. Then from (1) the intensity of the distributed load is:

$$q = \frac{m_{\Sigma} \cdot a \cdot h \cdot 2}{2{,}75 \cdot l} = \frac{1456 \cdot 0{,}8g \cdot 0{,}89 \cdot 2}{2{,}75 \cdot 2{,}065} = 3578\ \text{N/m},$$

here 2,75 m is arm of the force Q.

The dynamic pressure from distributed load across the 1,19 m panel width b is equal P_{dyn} = 3006 Pa; the static pressure due to gravity over the panel area A (A = 4,91 м^2) is equal to P_{stat} = 2906 N/m^2. Taking into account the technical characteristics of the pressure belts, the tension force of one belt T_{belt} = 3000 N = 300 daN. The uniform vertical pressure, taking into account 6 pressure belts is equal to P = 9885 Pa. The 13 panels' mass per one area unit m_{13} = 297 kg/m^2.

Using the software complex ANSYS it was developed the finite element model (Fig. 4) of the transported cargo. The model considered the peculiarities of the panel geometry and of its loading during the transportation process. As the sandwich panels have a three-layer structure of two cover metal sheets and a layer of insulation between them, the geometric model consists of three materials: steel, mineral wool, foam plastic (pads under the panels). The metal layer was modeled by the SHELL181 element, the inner layer - mineral wool and foam pads - by the SOLID185 element. To set the inertial loads, the SURF154 element was used. The total number of model finite elements was about 5000.

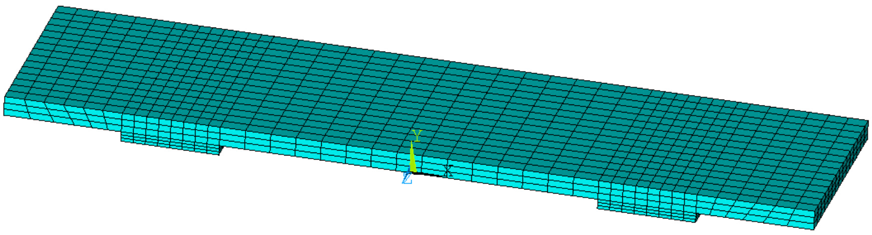


Fig. 4 The finite element model of the sandwich panel with supports

For calculations it was assumed that the steel elastic modulus is equal to 200 GPa, the mineral wool elastic modulus – 3 MPa, the elastic modulus of the foam with the bottom panel laid on it – 10 MPa. The gravity force G, the frictional force F, the unevenly distributed load Q were taken as the acting applied loads. For the stresses calculations there were considered cases with different number of panels in the piles. The distributed friction application was performed using the SURF154 surface effect elements and the constants were specified for the nodes belonging to the metal plates.

The stress-strain state of the bottom panel was calculated for the cases of the applied forces action on a different number of panels placed above it. Figure 5 shows the distribution of the von Mises equivalent stresses in the mineral wool for the pile of 13 panels. The presented scheme shows that the highest stresses occur at the boundary of the foam support.

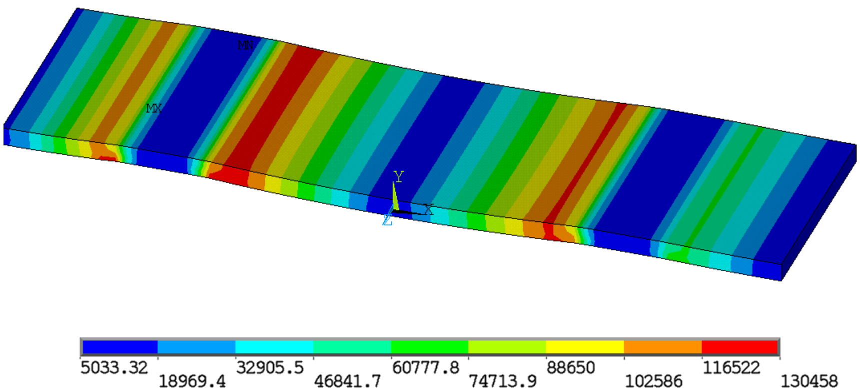


Fig. 5 The distribution of the von Mises equivalent stresses along the panel for the case of 13 panels in the pile

The performed calculations showed a gradual decrease in the stress level at the number of panels decrease. Fig. 6 shows the diagram of the maximal equivalent stresses in the mineral wool of the lower panel tier depending on the number of panels. The results of the calculations show that the stresses do not exceed the strength of the mineral wool at the pile height of 9 panels. This height corresponds to the declared by manufacturer transport package height of 1.5 m.

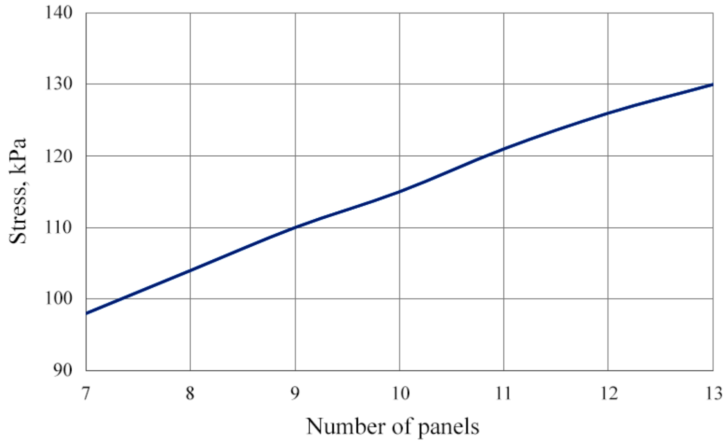


Fig. 6 The dependence of maximal stresses in the mineral wool on the number of panels in the pile

4. Conclusions

The obtained results show that the deformation of the transport package caused by the small elasticity modulus of the mineral wool and by the straps' tension forces change due to the car uneven movement lead to the oscillations of the transported cargo causing the panels' displacement inside the transport package.

The tension forces of the fixing straps calculated in accordance with the norms [3] should ensure the motionless of the rigid body of the similar dimensions. However, to analyze the strength of a cargo by the same rules, it is necessary to take into account the effect of doubled vertical dynamic loads. The finite element modeling of deformation of the bottom tier lower panel showed that the coupled action of the named forces results in tensile stresses in the mineral wool exceeding tensile strength for the case of ten or more panels in the package. To avoid the cargo damage in the case of transportation over long distances using the existing cargo transportation scheme only the rigid packing of the lower tier should be ensured.

References

1. **Davies, J.M.** 1993. Sandwich panels, Thin-Walled Structures 1-4(16): 179-198.
2. **Shmelev, A.** 2017. "Deceptive" stretch film, Compass of Forwarder and Carrier 6: 28-32 (in Russian).
3. EN 12195-1:2010. 2010. Load restraining on road vehicles. Safety. Calculation of securing forces. London: BSI, 52 p.
4. International Guidelines on Safe Load Securing for Road Transport. 2014. Geneva: IRU, 76 p.
5. **Singh, P.; Singh, J.; Antle, J.; Topper, E.; Grewal, G.** 2014. Load Securement and Packaging Methods to Reduce Risk of Damage and Personal Injury for Cargo Freight in Truck, Container and Intermodal Shipments, Journal of Applied Packaging Research 1(6): 47-61.
6. **Juvet, M.; Esprit, E.; Bergehe, G.V.** 2018. On Horizontal Dynamic Effects on Palletized Goods during Road Transport, Packaging Technology and Science 5(31): 310-330.
7. **Cieśla, M.; Hat-Garncarz, G.** 2013. The problem of proper cargo securing in road transport – case study, Transport Problems, 4(8): 27-33.
8. **Lehtinen, M.** 2014. Terästuotteiden kuljetus erikoiskonteissa - Opinnäytetyö. Kotka: Kymenlaakson ammattikorkeakoulu, 46 s. (in Finnish).
9. **Chaganova, O.S.; Varazhun, I.A.** 2018. Fastenings parameters determination for highly deformative cargo, taking into account its durability during transportation in cars and Trains, International Journal of Mechanical Engineering and Robotics Research 3(7): 218-222.
10. **Kuzniatsova, M.; Shimanovsky, A.** 2016. Definition of rational form of lateral perforated baffle for road tanks, Procedia Engineering 134: 72-79.
11. **Škes, L.; Jelenić, G.** 2014. Analysis of a geometrically exact multi-layer beam with a rigid interlayer connection. Acta Mechanica 2(225): 523-541.
12. **Starovoitov, E.I.; Leonenko, D.V.; Yarovaya, A.V.** 2007. Elastoplastic bending of a sandwich bar on an elastic foundation, International Applied Mechanics 4(43): 451-459.
13. **Osadchy, N.V.; Shepel, V.T.** 2014. Analytical research of transverse bending of a three-layer panel with a soft core, Herald of Irkutsk State Technical University 5(88): 37-43 (in Russian).
14. **Zakharchuk, Yu.V.** 2017. Displacements in the circular three-layered plate with a compressible filler, Mechanics: Reaearches and Innovations 10: 55-66 (in Russian).
15. **Pleskachevsky, Yu.M.; Starovoitov, E.I.; Yarovaya, A.V.** 2004. Dynamics of metal-polymer systems. Minsk: Belaruskaya Navuka, 385 p. (in Russian).
16. **Iváñez, I.; Moure, M.M.; Garcia-Castillo, S.K.; Sanchez-Saez, S.** 2015. The oblique impact response of composite sandwich plates, Composite Structures 133: 1127-1136.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Safety Method for Wireless Data Transmission in Control Command Systems

L. Sokołowska[1], A. Toruń[2]

[1]*Railway Institute, Railway Traffic Control and Telecom Unit 50, J Chłopickiego Street, 04-275 Warsaw, Poland, E-mail: Lsokolowska@ikolej.pl*
[2]*Railway Institute, Railway Traffic Control and Telecom Unit 50, J Chłopickiego Street, 04-275 Warsaw, Poland, E-mail: atorun@ikolej.pl*

Abstract

Control process of the railway traffic control requires providing the safety information exchange between railway control command devices. Mechanisms for providing safety of data transmission are conditioned by normative documents (PN-EN 50159). The article presents reasons for the loss of telegrams, risk prevention methods and issues regarding threats and remedies which increase the safety of transmission in control command systems. Examples of the possibilities of implementing cryptographic safety methods of transmitted data (according to PN-EN 50159) are presented, indicating time efficiency of processing telegrams.
KEY WORDS: *cryptographic security methods, transmission safety in control command systems*

1. Introduction

Process of railway traffic control requires ensuring a safe exchange of information between railway control command devices. The exchange of control information between devices is conditioned by time determinism and the need to ensure the required level of safety integrity level SIL [2]. In order to achieve the required level of safety, it is necessary to specify transmission tasks and the type of information sent. These assumptions should be taken into account at the stage of preparing information structures and their coding. Communication process used to control command devices can be implemented in an open or closed transmission system. This division results from the paragraphs contained in the standard PN-EN 50-159:2011. It defines, i. a. requirements and recommendations for safe communication in transmission systems and the means and methods necessary to achieve it. The term a "closed system" in the transmission system should be understood as a network in which the type and structure of data is determined at the stage of creating the system, and the number of network data is constant and does not change in the process of system operation. In such a system, only authorized access is assumed, the maximum number of connection participants (devices) is known and the transmission medium is known which must be permanently connected. This means that for safety reasons, the probability of unauthorized access is considered negligible [2]. In turn, in "open system" the number of network data changes during the system operation, in such a system may appear data unrelated with the system. In such systems, transmission is carried out using a wireless network, or through shared links with public access. Threats to telegrams in both the "closed system" and the "open system" may occur as a result of possible changes in the implementation of the connection at the user or external environment level. The causes of threats result mainly from the determination of the variable and the unknown number of users in the transmission systems and the flexible format of the transferred data. In "open systems" of the transmission system, data used for communication, from the safety point of view, should be treated as unreliable, exposed to various types of threats i. a. on deliberately or unintentionally "impersonate" another system, or attacks to gain access to transmitted data or transmit processed telegrams. As a consequence, from the point of view of railway control command safety, the main threat in the communication system between control command devices is the failure of the recipient not to receive a valid and authentic telegram or falsification of its contents. The risk of losing a telegram can be caused by: corruption, deletion, repetition, delay, change of the transmitted telegram order, or appearance of an unauthorized telegram. In order to prevent such stage of, appropriate safety measures should be taken. The PN-EN 50159 [2] standard mentions the following safety functions in this regard:

- numbering of telegrams and sequence control of numbers (sequence number);
- determination of the maximum waiting time for confirmation of telegram reception (time-out);
- transmission time control of telegrams (time stamp);
- the use of sender and recipient identifiers in telegrams (sender and receiver ID);
- using user or application authorization procedures (recipient), which ensures protection and confidentiality of information against unauthorized access and modification (authorization);
- the use of data coding and encryption techniques, which allows to ensure the integrity of information (e.g. CRC) or hash functions, that allow detect of errors or deliberate change of telegram content (authentication and cryptography).

2. Definition of Transmission Safety in Norm PN-EN 50-159:2011

The implementation of the connection for transmission of telegrams between railway control command devices

must be made in such a way that it is possible to detect errors in the telegram as soon as possible. However, the interruption in the transmission channel must cause transition the system to "safe state", in accordance with the procedure determined individually for particular types of systems. In order to guarantee proper operation of the railway control command system, measures should be taken to prevent loss or misrepresentation of the telegram, which may result from disturbances or unauthorized actions by third parties. The open transmission system implemented in the railway control command system using public radio networks must ensure the required level of safety (complies with classification SIL resulting from the PN-EN 50 129 standards) not worse than the level of safety in existing systems. Figure 1 presents the classification of transmission protections in a closed and open system in accordance with the PN-EN 50159 standard.

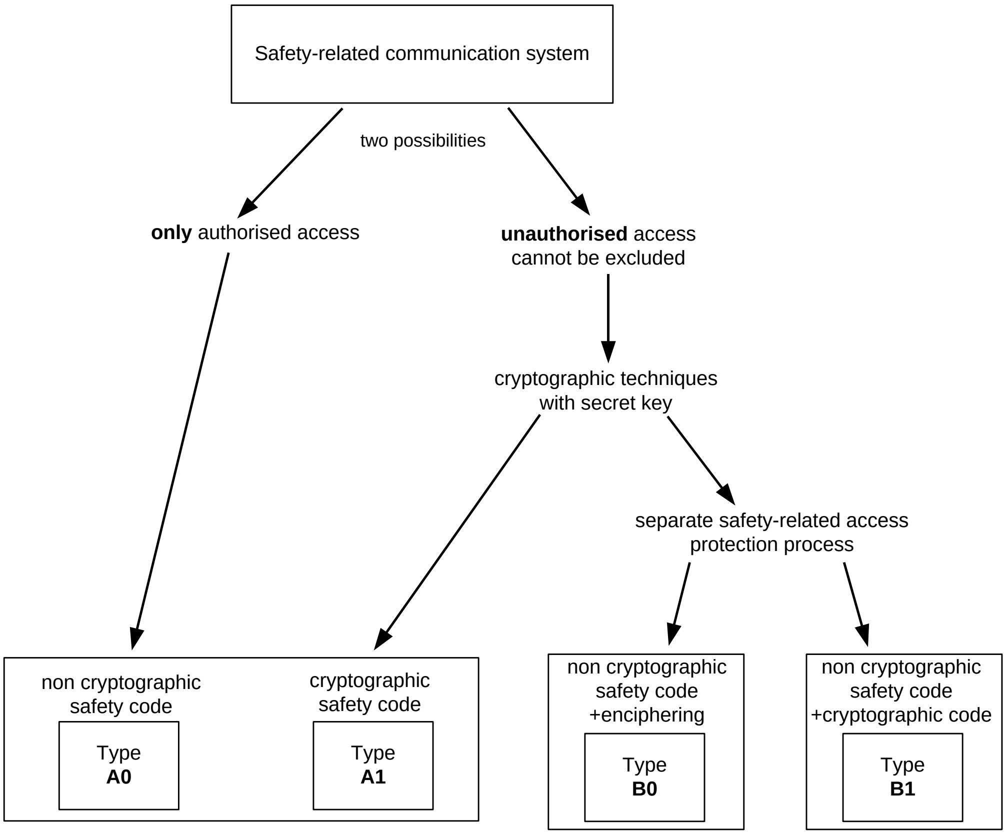


Fig. 1 Classification of transmission protections for transmission systems in accordance with the PN-EN 50159 standard [2]

The following transmission groups have been defined on the basis of the principles of sending telegrams and methods of their protection [2]:

- **A0** - only authorized access, data integrity code required, no cryptographic security code required;
- **A1** - the use of unauthorized access is not excluded, a cryptographic security code is required;
- **B0** - the use of unauthorized access is not excluded, encryption is required, no cryptographic security code is required;
- **B1** - the use of unauthorized access is not excluded, cryptographic code is required, cryptographic security code does not need to be used.

Table 1

Threats and remedies according to the PN-EN 50159 standard

Threats	***Defences***							
	Sequence number	**Time stamp**	**Timeout**	**Source and destination identifiers**	**Feed-back message**	**Identification procedure**	**Safety code**	**Crypto-graphic techniques**
Repetition	X	X						
Deletion	X							
Insertion	X			X	X	X		
Re-sequence	X	X						
Corruption							X	X
Delay		X	X					
Masquerade					X	X		X

Source: [2]

The standard also lists the threats to which transmission of telegrams is exposed in an open transmission system, caused by various possible reasons, from sabotage to environmental factors and provides a set of technical measures to protect against identified threats. Threats and remedies are presented below in Table 1.

3. Safety Measures Increasing Security in Open Transmission Systems

When confronting the threats listed in Table 1 with the remedial measures, the following conclusions regarding adequate preventive methods to increase the security of data transmission in wireless control systems of railway control command devices can be formulated. The use of a sequential number in the transmission of telegrams prevents such threats as: repeating, deleting, inserting or changing the order of datagrams. Assumed possible deletion and spontaneous formation of telegrams can, at the use of this protection, induce, at most, retransmissions or exceeding the waiting time limits for the telegram. Changing the sequence of telegrams is intrinsically immediately detected and does not lead to incorrect system operation, while quite troublesome damage (or sabotage) consisting in repeating the correct (syntactically) telegram that does not reflect the proper state of the system can even be detected only by the sequential number. In addition, the use of this procedure allows to track and record the nature of the communication problem, because frequent repetition of the sequence number points to a transmission channel failure, and frequent loss of sequential number continuity indicates poor operating conditions of the radio (or wired) channel.

Protection of telegrams against damage requires, according to the standard, an additional security code or cryptographic techniques. A good proposal for cryptographic security is encryption with the AES algorithm. Protection against delay of telegrams is a mechanism of limit waiting times for a telegram and time stamps, which enable logging system events for a possible eventual analysis of system failures. Admittedly, the aforementioned security features: sequential number, encryption, security code, timeout mechanism and timestamp correspond to all threats listed in Table 1, but it is advisable to use additional mechanisms increasing transmission security in open systems, in particular with dynamic system configuration. They also include unique sender and recipient identifiers in telegrams as well as procedures for identifying (authorizing) communication participants [1, 3]. These mechanisms increase the ability to verify telegrams, reduce the risks associated with incorrect sending of system telegrams to bad recipients (system components) and increase security from masquerade. Unambiguous identification of communication participants is also a valuable mechanism supporting post-mortem analysis of registered system events.

4. Cryptographic Security and Analysis of Telegrams Encryption Efficiency

The observed development of ICT technologies, understood here as ICT devices and software, intensifies the interest in the development of methods for cryptographic security of transmitted data. The efficiency of encryption, a complex mathematical operation, often becomes a "bottleneck" during information exchange, therefore the use of encryption mode allowing parallelization of calculations improves the efficiency of processing telegrams. As already mentioned, for good transmission security it is desirable to use both encryption and authentication of telegrams. Traditionally, these operations were performed sequentially - first by encrypting and then creating an authentication code. Methods of securing telegrams, as recommended in the standard, are often used, for example, CRC redundancy codes used to detect accidental individual or serial errors, and as methods of authorization, the MD5 and SHA - 1 methods are recommended as the AES encryption method. The various mechanisms for ensuring the telegram transmission are presented above, for several reasons, the most important ones are: the requirements of standards, the coding efficiency and the processing time of the telegram. In railway control command systems, the first two (reasons) are mandatory, while time is an attribute that can be adjusted by selecting appropriate methods to adapt it to the parameters of the control system. In control systems, a general requirement is assumed that the service time of telegrams is "short enough", i.e. meets the system's performance expectations.

In order to observe the time differences in servicing telegrams and the effectiveness of particular methods of securing telegrams, simulations of encryption algorithms and checksums were carried out. These simulations were carried out for different sizes of telegrams and for 1000000 telegram processing cycles. The following drawings show an image of the simulation screen containing simulation results - Fig. 2. and their graphical presentation in the form of a bar graph - Fig. 3.

Analyzing the obtained simulation results, it can be stated that the processing time of a telegram depends on its size and the encryption algorithms used. When comparing, for example, encryption algorithms: AES with ECB (Electronic Code Book) and AES with CBC (Cipher Block Chaining) mode, it can be concluded that the processing time of AES encrypted telegrams for the same telegram size is comparable. However, the size of the telegrams affects the processing time. In practice, with regard to control command systems, it can be assumed that the processing time of telegrams at the level of 30 ms does not introduce significant delays into the system, which does not exclude the use of proposed encryption methods to ensure confidentiality and authentication of telegrams in control command systems.

5. Summary

The idea of the article was to present problems appearing in open transmission systems, to which manufacturers of railway control command systems are increasingly willing to use, methods of ensuring security in these systems, which are an alternative to physically and logically separated "railway" transmission channels. Since the exchange of control information (commands and reports) between control command devices is conditioned by time determinism, it

forces the selection of appropriate methods of telegram encryption to ensure the required level of security integrity SIL.

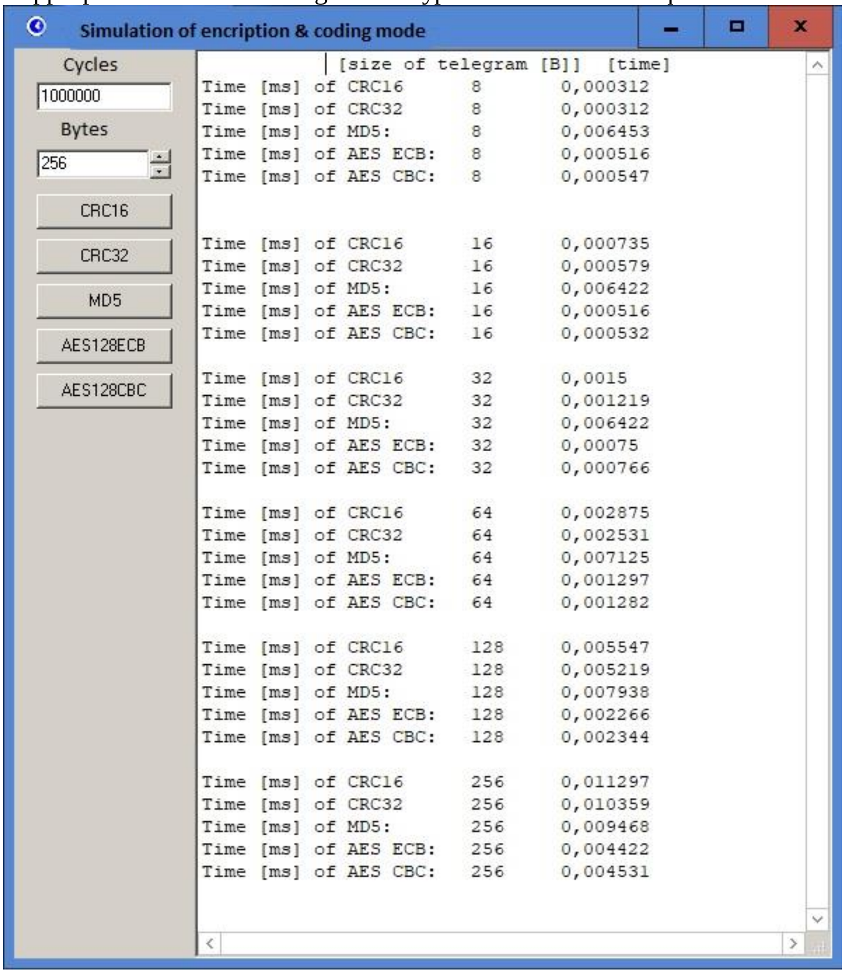


Fig. 2 Report of the coding and encryption mode with example results of the process duration

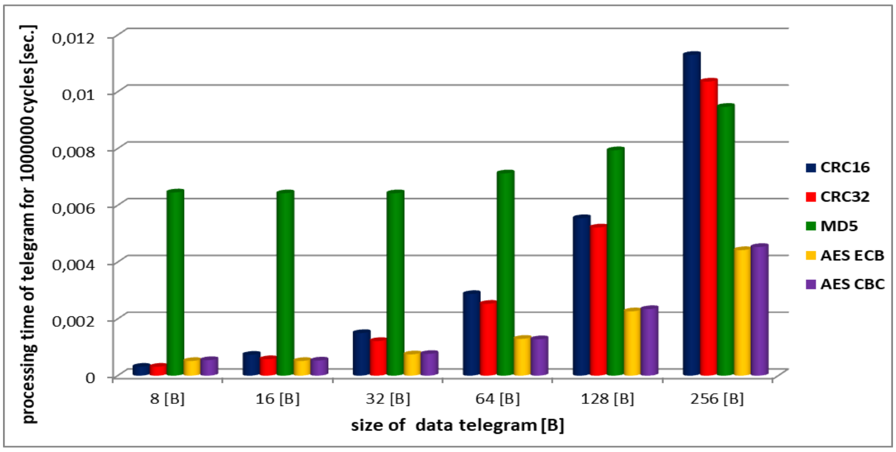


Fig. 3 Graphical presentation of obtained simulation results

References

1. **Bester, L.; Toruń, A.** 2014. Modeling of Reliability and Safety at Level Crossing Including in Polish Railway Conditions, Communications in Computer and Information Sience (471) (Telematcs – Support for Transport), Springer-Verlag Berlin Heidelberg, 14th International Conference on Transport System Telematics, TST 2014.
2. PN-EN 50159:2011 "Railway applications - Communication, signalling and processing systems-Safety-related communication in transmission systems".
3. **Sumiła M.** 2016. Risk Analysis of Interference Railway GSM-R System in Polish Conditions, Advances in Intelligent Systems and Computing 470: 469-478, 11th International Conference on Dependability and Complex Systems (DepCoS-RELCOMEX), Brunow, POLAND, JUN 27-JUL 01, 2016.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Market of Transport Services in Poland - the Analysis of Changes of the Subject Structure

B.Zagożdżon[1], P.Sołtys[2]

[1]*Kazimierz Pulaski University of Technology and Humanities, Malczewskiego 29, 26-600, Radom, Poland, E-mail: b.zagozdzon@uthrad.pl*

[2]*Kazimierz Pulaski University of Technology and Humanities, Malczewskiego 29, 26-600, Radom, Poland, student*

Abstract

Transport and economy interact with each other, and the increase of production generates the increase of demand for transport of goods. After the crisis in 2009 and the collapse of the market, we can observe a gradual improvement of the economic situation, and thus the increase in transport. The transport market in Poland is developing dynamically, and the logical consequence of the increase of the volume of transport are changes of the subject structure of the market.

The article presents the results of the analysis of the subjective structure of the transport market in 2009-2016. The following elements were the subject of the research: a number of business entities and the legal form of their activity, the size of companies, the value and structure of fixed assets. Moreover, selected financial indicators have been presented, bearing in mind the influence of changes of the market subjective structure on the financial condition of companies.

KEY WORDS: *transport, freight transport, transport company*

1. Introduction

Transport is a necessary element of the proper functioning of the economy and is often called its carrying system or the lifeblood. Transport and the economy interact with each other and the increase in production generates an increase for the demand for freight transportation. After the crisis and the collapse of the market in 2009, we can observe a gradual improvement in the economic situation, and thus an increase in transport. In 2009-2015, total transport in the EU-28 increased by 7% (3 291 to 3 516 billion tkm). In Poland, this increase was definitely higher and amounted to 21% [1]. It is worth emphasising that Polish road transport is a leader in international transport in the EU. Since 2010 it has been ranked first ahead of the countries that had previously dominated - Spain, Germany and the Netherlands.

The Polish transport market is therefore developing dynamically. In this context, an interesting research problem is the analysis of the subject structure of the market and possible changes caused by the increase of the volume of transport. This is the main purpose of this article. The subject of the research were the following elements of the subjective structure: the number of enterprises, their size and legal form of their activity. The structure of fixed assets of enterprises was also analysed, because it plays a fundamental role in their functioning and determines the efficiency of operations. In the last stage of the research selected financial indicators were presented, bearing in mind the impact of the growth of transport on the economic condition of enterprises. The undertaken research covered the years 2009-2016, the period of emerging from the crisis, and then - stabilizing the economy. The analysis, in the first place, concerned the entire transport and storage sector, and then only road transport, because it transports the most goods.

In the study the qualitative and quantitative methods were used which increase the accuracy of the obtained results and the conclusions formulated on this basis. The method of comparative analysis as well as statistical analysis and analysis of cause and effect relationship were applied. The data of the Central Statistical Office in Poland, Eurostat and the European Commission were used as empirical material for statistical analyses.

2. General Characteristics of Cargo Transport

The basic analysis of the subject structure of the market will be preceded by a synthetic characterization of cargo transport, because it is one of the main determinants of the functioning and development of enterprises. The transport market is defined in Poland as the transport-forwarding-logistics market, in short TFL. This term is adequate to the types of activities carried out by enterprises. The companies, competing with each other, expand the scope of services provided. They mainly provide transport services, but also provide forwarding and logistics services, e.g. storage.

On the freight transport market in Poland, the tendency of constant growth continues (Figs. 1 and 2). This increase measured in the number of tonne-kilometres was 36% in the years 2009-2016. The highest dynamics occurred in road transport - an increase of 58%. However, the weight of transported cargo increased by only 7%. This disproportion between the indicators shows that the average transport distance has significantly increased.

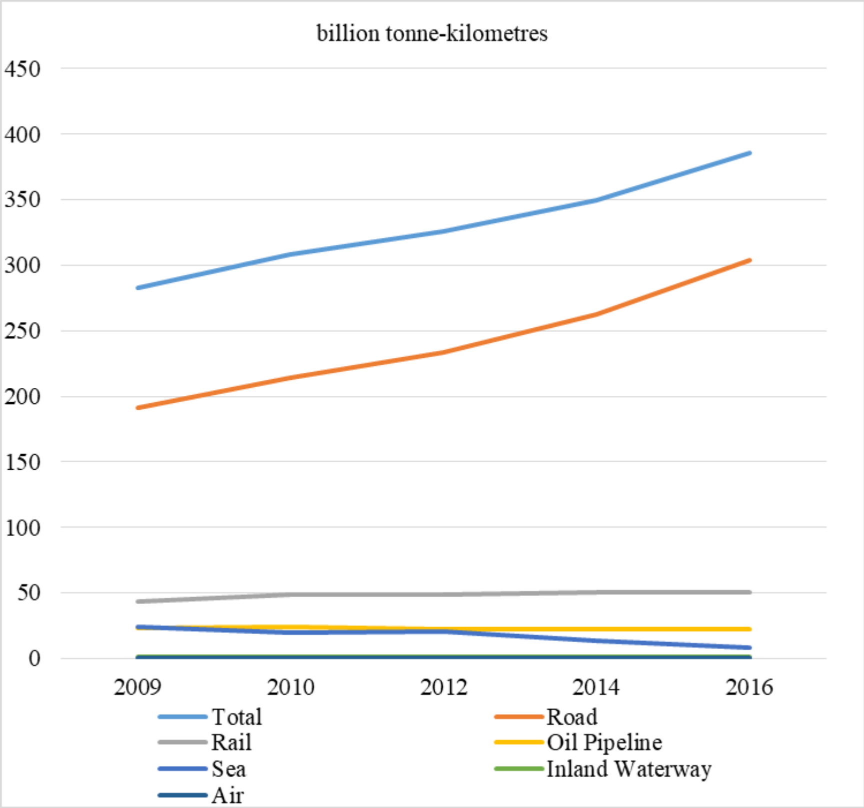


Fig. 1 Transport of Goods (in tonne-kilometres) [2]

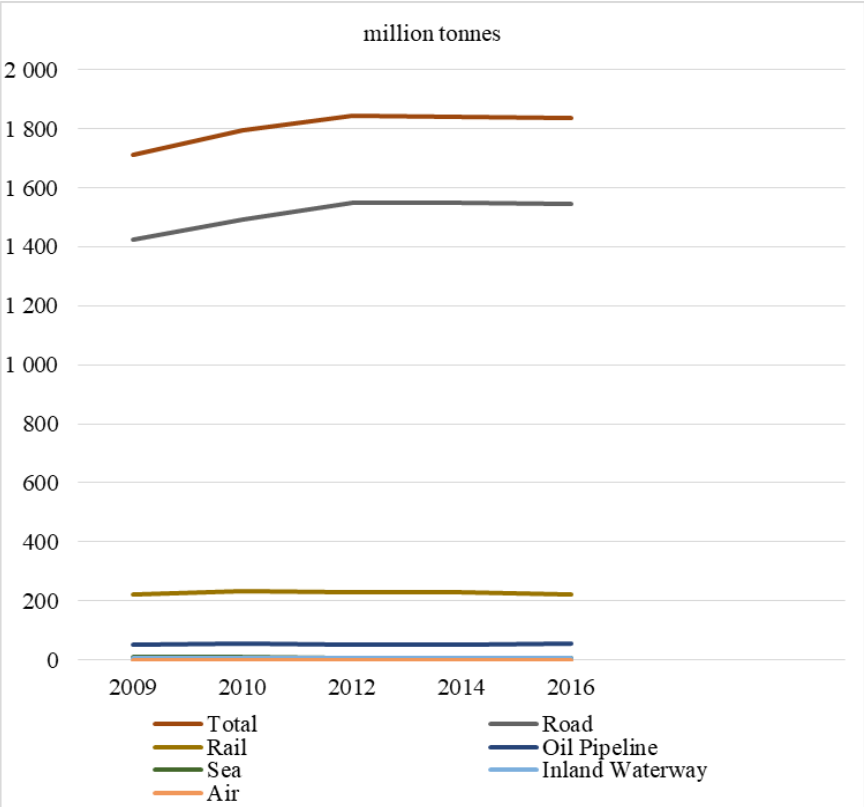


Fig. 2 Transport of Goods (in tonnes) [2]

Similarly as in all EU countries, road transport is a leader on the freight transport market - its share in 2015 in the EU was 72% (tkm, without shipping), and in Poland - 76% [1]. The dominant position of the road transport is determined by its technical and operational features, one of which is of fundamental importance - the possibility of providing services in the "door-door" relation. Some of them can be mentioned here, for example: a relatively short and flexible delivery time, good adjustment of means of transport to the type of transported goods, varied load capacity.

3. The Subject Structure of the Market

The first stage of the analysis of the subjective structure of the market is the number of enterprises operating in the transport and storage sector (Fig. 3). The increase in the volume of transport did not influence the general increase of the number of entities. Their number is variable, however the difference between the maximum size in 2010 and the year 2012, in which there were the least, was only 4%. This cannot be considered as a breakdown of the subjective side of the market, because it is still a very competitive market, where services are offered by 253 to more than 260 000 companies. Most companies operate in road transport. It is estimated that their number is about 230 000, which accounts for 89% of all entities in the transport and storage sector.

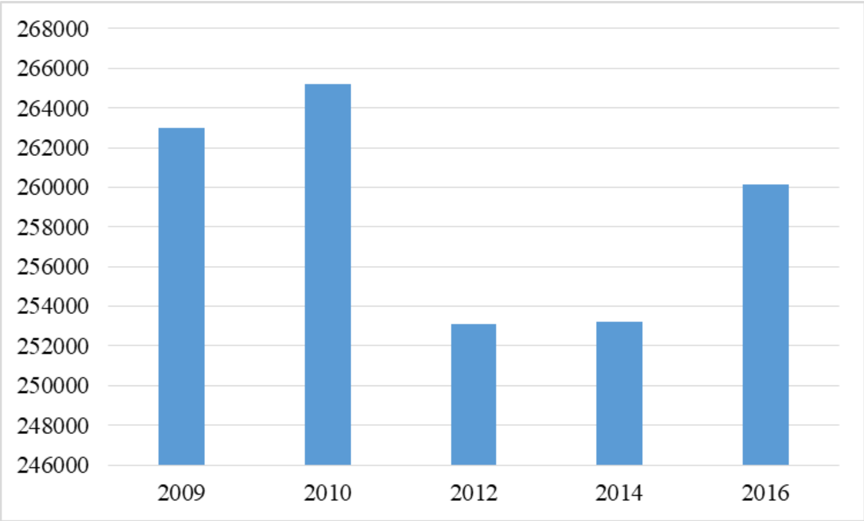


Fig. 3 Enterprises of transportation and storage [2]

Another element of the analysis is the form of ownership and the legal form of the functioning of enterprises. With regard to the legal form, we can distinguish: economic activity conducted by private individuals, commercial companies, cooperatives and state enterprises (Fig. 4). The largest number of entities functions as an economic activity conducted by private individuals - 88%. This is a legal form characteristic for small and medium-sized private companies. However, large private enterprises function as commercial companies and constitute 8% of all entities. In 2009, there were 20 state enterprises and 150 cooperatives. However, in 2016, there were respectively: 6 and 144 cooperatives (such a small number was not taken into consideration in the figure) [2]. The process of liquidation or transformation of state enterprises into other proprietary and legal forms has been proceeding for years and results from the doctrine of the state's economic policy.

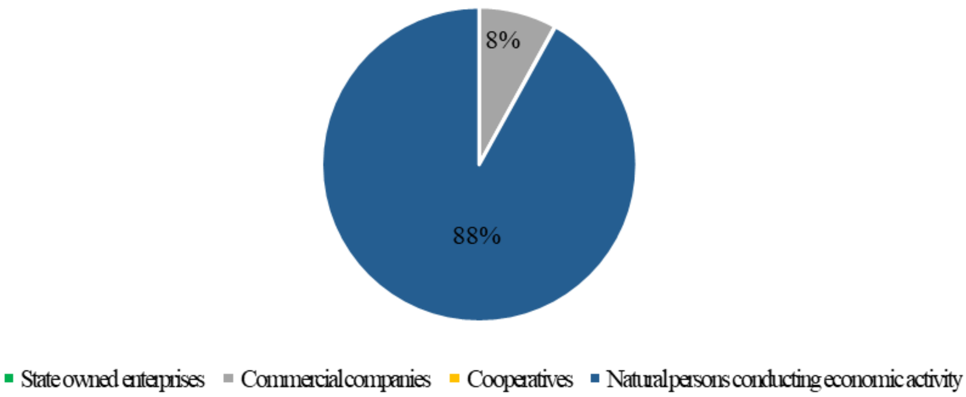


Fig. 4 Enterprises of transportation and storage by legal status [2]

As far as the size of companies is concerned, the transport and storage market is dominated by private microenterprises that employ up to 9 employees. These companies operate mainly in the field of road transport. The detailed subject structure of this branch of transport is as follows [3]:

- companies employing up to 9 people – 97,7%;
- companies employing from 10 to 49 people – 1,9%;
- companies employing from 50 to 249 people – 0,3%;
- companies employing over 250 people – 0,1%.

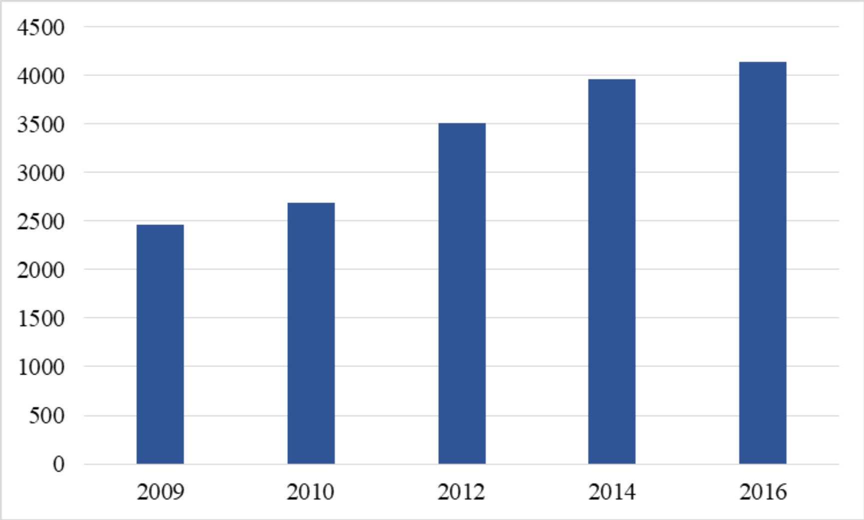


Fig. 5 Road transport enterprises employing more than 9 persons [3]

Medium and large enterprises that employ more than 9 employees account for only 2,3%, and their number in 2016 was 4 146 entities (Fig. 5). It is worth highlighting that the number of companies in this group increased in 2009-2016 by 68%. The high rate of dynamics indicates the development of the segment of medium and large private enterprises in road transport.

4. The Structure of Companies' Fixed Assets

Enterprises conducting business activity and fulfilling specific tasks must have adequate fixed assets. It plays a fundamental role in their functioning, because well-adjusted financial resources enable achievement of the intended aims. Effective management of fixed assets determines the efficiency of companies' operations, their competitiveness and development opportunities. In the management process, the level of investment is vital because it influences the value of fixed assets, their technical condition and the degree of wear. Practice shows that in transport companies, the condition and age structure of rolling stock determines the quality of the transport offer, and this in turn the company's competitiveness on the market and the volume of transport. Tables 1 and 2 present the indicators of dynamics of investment outlays and gross value of fixed assets as well as the degree of consumption of fixed assets in enterprises of the entire transport and storage sector, and then in road transport companies. In order to maintain the comparability of data, the analysis was completed in 2015. At present, there are no data for 2016 for the analysed indicators in road transport, because these data are published every two years.

Table 1

Dynamics of investment outlays, gross value of fixed assets and the level of consumption in transportation and storage (%) [2]

Specification	2009	2010	2011	2012	2013	2014	2015
Dynamics of investment outlays	25,7	14,1	24,8	-8,2	-15,7	3,9	13,0
Dynamics of gross value of fixed assets	3,7	4,2	4,9	4,0	4,8	5,0	5,3
The level of consumption of fixed assets	52,3	50,2	47,6	45,4	44,2	44,6	44,3

Table 2

Dynamics of investment outlays, gross value of fixed assets and the level of consumption in road transport (%) [4]

Specification	2009	2010	2011	2012	2013	2014	2015
Dynamics of investment outlays	-39,4	36,9	67,0	-13,8	-10,0	35,9	14,6
Dynamics of gross value of fixed assets	6,5	5,8	11,7	8,7	6,7	10,5	11,5
The level of consumption of fixed assets	52,8	53,0	50,4	48,9	49,1	48,0	46,6

Analysing data to the entire transport and storage sector, one can notice a diversified dynamics of the level of investment outlays. In 2012-2013, there was a decline caused by the collapse of the economy. However, what is important is the fact that the level of investment ensures a continuous increase of the gross value of fixed assets, and thus reducing their level of consumption. A similar tendency exists in road transport, however, the dynamics of these two indicators is definitely higher there (Table 2). Investment outlays, and thus the gross value of fixed assets - mainly means of transport, increase faster in road transport than in the entire TFL sector. In practice, this means that companies invest in rolling stock, which shows their good economic condition and development. In 2009-2015, the number of lorries increased by 20%, while truck tractors by 64% (Fig. 6). Investments of road transporters are fully justified and

needed, because the level of consumption of fixed assets, despite the declining trend, is however higher in comparison to the entire transport and storage sector.

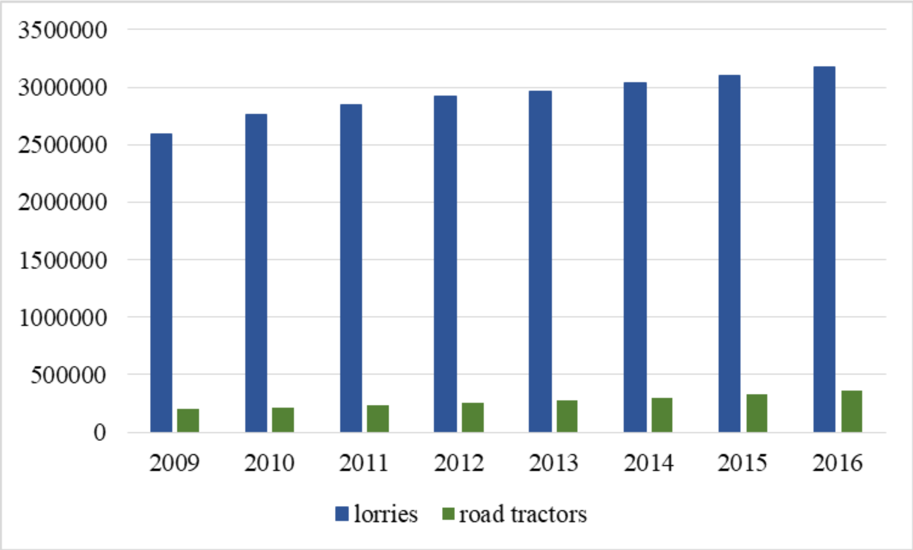


Fig. 6 Lorries and road tractors in road transport [4]

5. Profitability of Companies

One of the main goals of companies is to generate profit. The level of profit achieved in the following years, especially its dynamics, is used to assess the management processes in the company, its economic situation, position on the market as well as for self-control and self-assessment of its own operations. Therefore, in the conducted studies, the profitability of gross turnover (sale) was taken into consideration as one of the basic indicators of the economic and financial analysis. Profitability indicator informs about how much profit (before tax) all income generates from their activity (Table 3). It shows the effectiveness of property management, link between the achieved financial result and income from company activity, resources and equity.

Table 3

Profitability indicator (%) [2, 4]

Specification	2009	2010	2011	2012	2013	2014	2015
Gross turnover profitability indicator in transportation and storage	1,6	2,5	2,4	2,5	3,1	4,6	4,4
Gross turnover profitability indicator in road transport	2,2	4,0	3,6	2,6	3,0	3,3	4,0

The increase of the profitability indicator is characteristic for the entire transport sector and storage economy, which indicates the good economic condition of the TFL enterprises. In road transport, high profitability can be observed in 2009-2012 compared to the entire sector. However, since 2013 this indicator has been below the average value and in 2015 it was 4%. Its level varies within the industry, and depends on the size of the company, the origin of the capital and the area of the main activity. The highest profitability in 2015 was in medium-sized companies employing from 10 to 49 people - 4%. In the case of the largest companies, the so-called TOP 10, the profitability ratio was 3,05%. Taking into account the origin of capital, the profitability of Polish carriers was at an average level of 3,6%, while companies with foreign capital reached only 2,5%. From the point of view of the main area of activity - logistic companies had the highest profitability – 3,4% and transport – 3,35%, and slightly lower forwarding companies - 3% [5].

In general, profitability in road transport companies for the entire sector has been below the average in recent years. Several factors contributed to this, and two of them were the most significant: the closing of the Russian market, as a counterclaim for Western sanctions after Russia seized Crimea, and the introduction of a minimum wage for all employees in Germany or France, including Polish drivers. The first of them contributed to the collapse of trade with Russia and reduction of transport in this direction, while the second generated additional costs in companies.

6. Conclusions

The Polish transport market is a very competitive market, where about 260,000 companies offer services. Most of them operate in road transport - 89% of all entities. These are private micro-enterprises which employ up to 9 employees. The increase of the volume of transport did not affect the increase of the total number of TFL entities. Capital expenditures in total transport reach a level that ensures a constant increase of the gross value of fixed assets, which

leads to a reduction of their consumption degree. In road transport, the growth dynamics of these two indicators is above average values. In the group of medium and large companies there was an increase of the number of trucks and tractor units. In this group of entities, the number of companies has also increased. On this basis it can be concluded that this segment of the market is developing. As far as the economic condition is concerned, the profitability of the entire transport sector and storage economy is increasing. However, profitability in road transport companies is below average, and the value comparable with the entire sector is obtained only by companies operating in the field of logistics.

The challenge for the development of TFL companies, especially road transport companies, is currently the so-called mobility package, introduced by the European Commission. It contains 8 legislative initiatives, 5 of which concern road transport. They include: sorting out the minimum wage for drivers, simplifying the rules regarding driving time and rest, changing the rules of cabotage, combating companies so-called "Mailboxes", transport by vehicles with 3,5 tons (maximum total permissible mass). For Polish companies this means the need for ordering many formal matters and increase of costs of services provided. There may be a decrease in the already low profitability as well as slowing down the development of enterprises, especially in international road transport. Therefore, further research into the subject-related structure of the market may include an analysis of the adjustment of companies to the new operating conditions, and then an analysis of the impact of these regulations on the subjective structure.

References

1. Statistical Pocketbook 2017. EU Transport in figures. Loxembourg: Publications Office of the European Union.
2. Statistical Yearbook of the Republic of Poland, 2010-2017. Warsaw 2010-2017: Central Statistical Office.
3. Transport. Activity Results in 2009-2016. Warsaw 2010-2017: Central Statistical Office.
4. Road Transport in Poland in the years 2009-2015. Warsaw 2011-2017: Central Statistical Office.
5. **Brdulak, H.** 2016. Stan równowagi (nierównowagi?) europejskiej i polskiej gospodarki, Dziennik Gazeta Prawna, 27 czerwca (in Polish).

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Improvement the Quality Management of Locomotives by Using the Live Cycle Costing Method

A. Dolinayova[1], L. Cerna[2]

[1]*University of Žilina, Univerzitná 8215/1, 01026, Žilina, Slovakia, E-mail: anna.dolinayova@fpedas.uniza.sk*
[2]*University of Žilina, Univerzitná 8215/1, 01026, Žilina, Slovakia, E-mail: lenka.cerna@fpedas.uniza.sk*

Abstract

The role of quality management in the field of rolling-stock in the railway transport is to manage the all processes related to investment, use, security, repair and maintenance, etc. with the aim to provide quality services in terms of customer orientation. Acquisition costs and use of locomotives generate the cost which structure has been different not only for different locomotives but also in each period of their use. These costs are an important part from the total company cost which provide the services in the railway freight or passenger transport. Therefore, decision-making process on the type of locomotives used is a strategic decision that has a significant impact to effectiveness of services. The paper deals with the estimation of annual locomotives costs by using Live Cycle Costing method. The suggested model takes into account different indicators influencing locomotive costs such as acquisition costs, driving locomotive output, performances, etc.
KEY WORDS: *live cycle costing, locomotives, operating costs, maintenance system, transport performances*

1. Introduction

Life Cycle Costing (LCC) is the method of costs calculation which take into account all costs related with product. It is the costs before, during and after production or rendition of services. In the transport sector LCC method is mainly used for calculation costs of automobiles but this method can be applied in the railway transport to manage the cost of railway vehicles or railway infrastructure. Life cycle assessment has been performed for the Mumbai Suburban Railway with the objective of developing a comprehensive methodology for environmental evaluation of suburban railway projects in terms of energy consumption and relevant impact categories [1]. The Life-Cycle Assessment Tool within the MAINLINE project is being developed to compare different intervention strategies for railway assets and provide outputs for both environmental impacts and economic costs to assist infrastructure managers throughout the European rail transport network [2]. Traditional transport Cost-Benefit Analysis commonly ignores the indirect environmental impacts of an infrastructure project deriving from the overall life-cycle of the different project components. Such indirect impacts are instead of key importance in order to assess the long-term sustainability of a transport infrastructure project. Manzo and Salling suggested to overcome this limit by combining a conventional life-cycle assessment approach with standard transport cost-benefit analysis [3].

Zhang et al. presented maintenance cost during the rail's life cycle [4]. Evaluation of all railway transportation systems should be possible using only Life Cycle Assessment/Life Cycle Cost methodologies [5]. It is a faster, more accurate system that improves the informed decision-making capability for life cycle cost management of railway bridges [6]. Urban Track is an EU funded research project (2006-2010) aiming at the development and construction of modular track systems for tram, metro and light rail with a low life cycle cost and a high performance [7]. Life cycle approach for urban guided transport systems with typical life cycle phase reduce the future efforts needs for new or upgraded urban guided transport systems [8]. A coupled LCC and Life Cycle Assessment has been performed for carbodies of the Korean Tilting Train eXpress project [9]. Bergerson and Lave examined the life cycle costs, environmental discharges, and deaths of moving coal via rail, coal gas via pipeline, and electricity via wire from the Powder River Basin in Wyoming to Texas [10].

All processes in the railway transport (from the planning project to the train transport organization) must be evaluate from the economic point of view [11]. The LCC methods can be applied in companies providing the rail freight and rail passenger services on all processes of providing the rail services [12]. By using Life Cycle Assessment/Life Cycle Cost methodologies it can increase quality of rail services [13] and total transportation chain [14]. With respect these it is possible apply LCC method to planning and management of locomotive costs during economic viability.

2. Materials and Methods

There is possible used many methods to cost calculation in the railway transport. The choice of the relevant method is dependent on cost unit, technological processes, organization and so on. The methods are different from the requirements of scope and structure of input data, process of create cost calculation and the possibilities to use of results of calculation point of view.

Currently, in the railway undertakings it is often used the LCC method. LCC is the total money that has to be spent on a product, process, activity, etc. during its existence [15].

This method takes into account all costs associated with the product as following:

- research and innovation;
- design;
- creating technological processes;
- technic and technical equipment for research, production and liquidations of production or services;
- investment costs;
- market introduction of the product/services;
- manufacturing;
- sale;
- marketing;
- liquidations of production or services (processed by [16, 17]).

The locomotives costs are an important part from the total company cost which provide the services in the railway freight or passenger transport. Locomotives are used in the transport processes a long time therefore the costs for regular and irregular maintenance are different during their using in the transport processes. Moreover, it is change also other cost mainly cost for energy consumption. Therefore, LCC methods is suitable for calculation and planning locomotives cost in the individual phases of their utilization. The using of LCC methods to prognosis and planning annual locomotives cost requires to know:

- investment cost;
- cost for regular repair and maintenance;
- estimation of cost for irregular repair and maintenance (e.g. in accidents);
- cost for certifications of locomotives in each countries which the locomotives will be used in;
- average energy consumption by types of locomotive and rail track conditions;
- price of electricity or fuel and so on.

The applications of LCC methods for planning annual locomotive cost can be realized by following approach:

- determination of depreciation methods and calculation of annual amortization amount;
- estimation of transport performances by market analysis (planning the number of passenger or quantity of goods, transport relations and their distance etc.);
- planning the turn-round of a locomotive;
- calculation of performances of locomotives;
- determination maintenance system (realize repair and maintenance by performances of locomotives or by time);
- determination/calculation the type and number of repair and maintenance in each year of use of locomotive;
- calculation annual cost of repair and maintenance of locomotive;
- estimation annual energy consumption of locomotive;
- calculation costs of energy consumption;
- estimation/planning total costs of locomotive.

This procedure should by applied separately for each type of locomotives. If the undertaking leases the locomotive, applications of LCC methods is simpler because all repair and maintenance costs are often included into rental price. Locomotives costs planning include only annual rental price, costs of energy consumption and possibly extra costs. Even in this case, it is advantageous to use LCC methods because different locomotives have a different cost and by using LCC costs methods can planning better expenditure.

3. Modeling the LCC Methods for Locomotive Cost

We were modeling the LCC method for multi-system locomotive and these basic parameters:

- linear depreciation method of locomotive investments;
- accounting depreciation period – 30 years;
- he system of repair and maintenance – by locomotive kilometers (we calculated 4 types of maintenance – ordinary – every 4.5 thousand locomotive km, small – every 32 thousand locomotive km, medium – every 280 thousand locomotive km and main – every 560 thousand locomotive km) [18];
- average energy consumption – 17 kWh for 1 000 gross tones km in the first years of use and increasing in the other years.

The number of repair/maintenance is different in individual years in regards of maintenance system (see Table).

The development of total cost of locomotives calculated by application LCC method shows the Fig. 1.

Table

Calculation costs of maintenance/repairs of locomotive

Year	The number of repairs/maintenances				Cost in thousand €		
	Ordinary	Small	Medium	Main	Maintenance	Energy consumption	Total
1	22	2	0	0	117,4	21,9	139,3
2	22	3	0	0	118,4	21,9	140,3
3	22	2	1	0	127,4	21,7	149,1
4	22	3	0	0	118,4	22,1	140,5
5	23	2	0	0	118,1	22,3	140,4
6	22	2	0	1	137,4	22,4	159,8
7	22	3	0	0	118,4	22,7	141,1
8	22	2	0	0	117,4	22,8	140,2
9	23	3	0	0	119,1	22,9	142,0
10	22	1	1	0	126,4	23,1	149,5
11	22	3	0	0	118,4	23,3	141,7
12	22	3	0	0	118,4	23,4	141,8
13	22	1	0	1	136,4	23,7	160,1
14	23	3	0	0	119,1	23,8	142,9
15	22	3	0	0	118,4	24,0	142,4
16	22	1	1	0	126,4	24,3	150,7
17	22	3	0	0	118,4	24,4	142,8
18	23	2	0	0	118,1	24,7	142,8
19	22	3	0	0	118,4	24,8	143,2
20	22	2	0	1	137,4	24,9	162,3
21	22	2	0	0	117,4	25,1	142,5
22	22	3	0	0	118,4	25,3	143,7
23	23	2	1	0	128,1	25,7	153,8
24	22	2	0	0	117,4	25,8	143,2
25	22	3	0	0	118,4	26,2	144,6
26	22	2	0	0	117,4	26,5	143,9
27	23	2	0	1	138,1	26,7	164,8
28	22	3	0	0	118,4	26,8	145,2
29	22	2	0	0	117,4	26,9	144,3
30	22	2	0	0	117,4	27,3	144,7

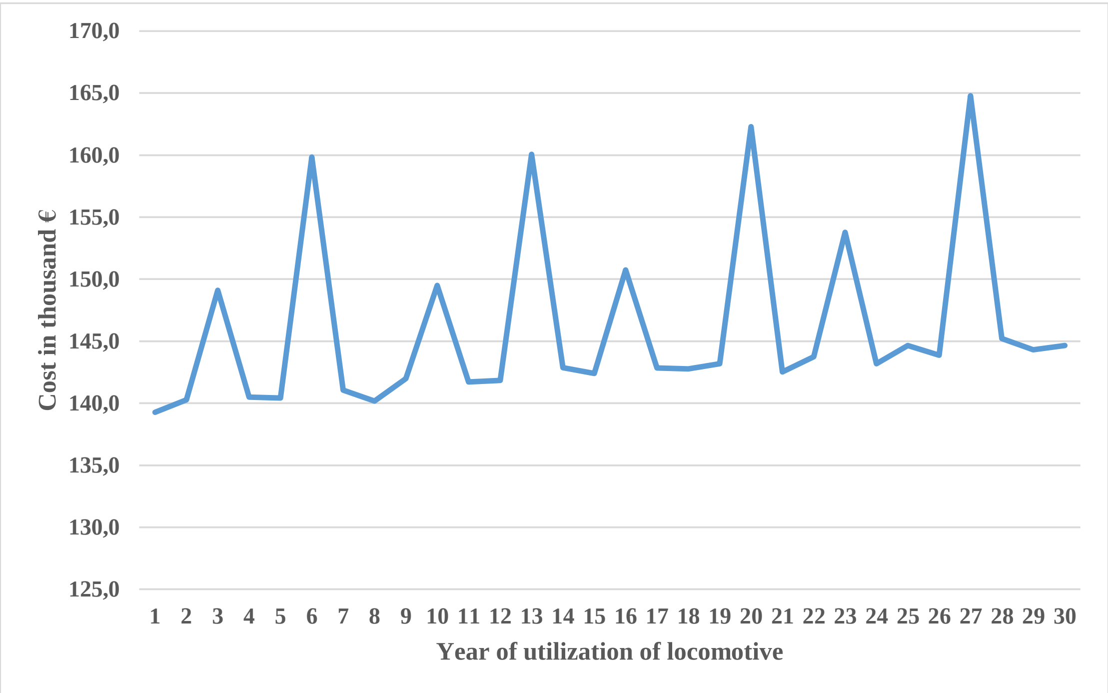


Fig. 1 Total costs of locomotive by LCC method

4. Results and Discussions

As can we see in previous chapter annual locomotives costs are influenced by number and costs of individual types of maintenance, depreciation, costs of energy consumption. The development of cost of locomotive has a growing character because repair and maintenance costs increase with the increasing age of locomotives and the average energy consumption also increase.

Other importance factors which influence the annual locomotive costs is maintenance system. In the Fig. 2 it is compared the annual cost of locomotives by using two maintenance systems - repair and maintenance by performances of locomotives and by time (determination the number of each tapes of repair/maintenance a year). We modeled the same total costs of locomotive during utilization.

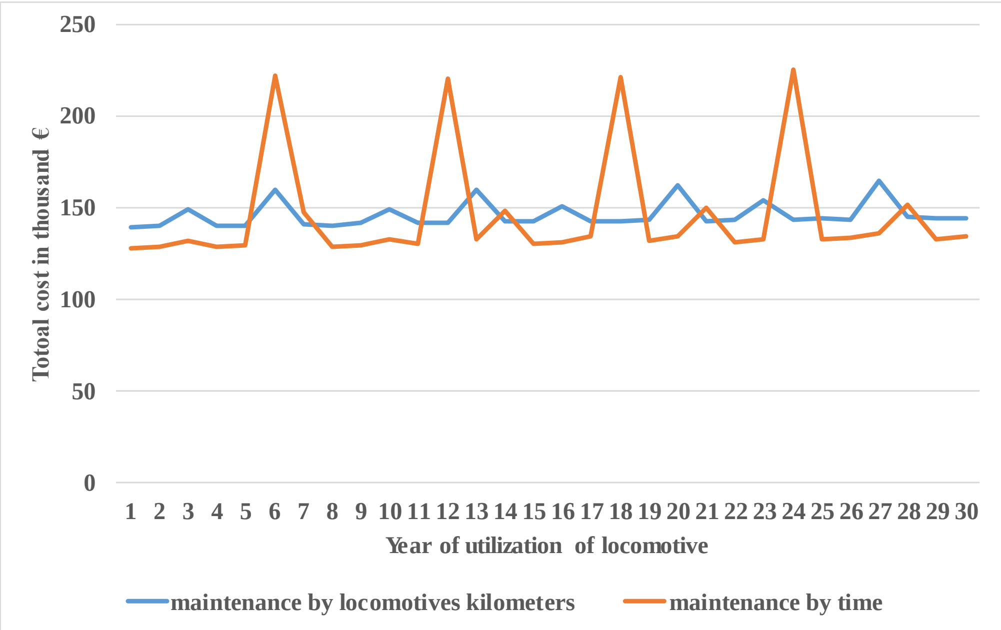


Fig. 2 Comparison of annual total costs of locomotive by using different maintenance system

As we can see in Figure 2 annual cost of locomotives are different if it is used different maintenance system. Differences between annual costs of locomotive are stronger if it is used maintenance system by time because the main repair/maintenance repeats itself periodically and the costs are the highest. This should be problem with financial planning of the company if the number of own locomotives is less than periodicity of main maintenance.

In our models we don´t take into account cost of irregular repairs because its costs are planned by previous analysis of these costs and it is not influenced by maintenance system.

5. Conclusions

LCC methods is useful tools to planning costs during all life cycle of products, projects, etc. In the rail undertakings which provide rail freight or rail passenger services this method can be applied not only to processes of providing services but also to estimation and planning cost of rolling stock. In view of the fact that economic life of locomotives is long application of LCC methods to estimation/calculation of annual locomotive cots can become a tool for better financial planning of companies. Using LCC methods for locomotives cost allows to plan repair and maintenance so that the total cost all locomotives will be approximately the same in individual time period of their using. Besides that, application of LCC methods to estimation/calculation of annual locomotive cots can be used as a supporting tool in decision-making about ownership or lease of rolling stock.

Acknowledgement

The paper was supported by the KEGA 010ŽU-4/2017 “New methods of teaching quality management in the study program Railway transport with a focus on optimization of extraordinary events in terms of customer orientation”, at Faculty of Operations and Economics of Transport and Communication, University of Žilina, Slovakia.

References

1. **Shinde, A.M.; Dikshit, A.K.; Singh, R.K.; Campana, P.E.** 2018. Life cycle analysis based comprehensive environmental performance evaluation of Mumbai Suburban Railway, India, Journal of Cleaner Production 188: 989-1003.

2. **Castlo, D.; Linneberg, P.; Puddicombe, R**. 2014. Life-cycle assessment tool for railway infrastructure, In 7th International Conference on Bridge Maintenance, Safety and Management (IABMAS). Shanghai, PEOPLES R CHINA JUL 07-11, 2014: 1064-1068
3. **Manzo, S.; Salling, K.B.** 2016. Integrating life-cycle assessment into transport cost-benefit analysis, Transport Research Arena TRA 2016, Book Series: Transportation Research Procedia 14: 273-282.
4. **Zhan, D.; Hu, H.; Roberts, C.** 2017. Rail maintenance analysis using Petri nets. Structure and Infrastructure Engineering 13(6): 783-793.
5. **Banar, M.; Ozdemir, A.** 2015. An evaluation of railway passenger transport in Turkey using life cycle assessment and life cycle cost methods, Transportation Research Part D -Transport and Environment 41: 88-105.
6. **Nielsen, D.; Raman, D.; Chattopadhyay, G.** 2013. Life cycle management for railway bridge assets, Proceedings of the Institution of Mechanical Engineers Part F-Journal of Rail and Rapid Transit 227(5): 570-581.
7. **de Jong, M.; Declercq, K.** 2012. Economic evaluation of urban track systems: integration of Life Cycle Costs and Socio-Economic Assessment, Transport Research Arena 2012, Book Series: Procedia Social and Behavioral Sciences 48: 1264-1273.
8. **Wigger, P.** 2012. MODSafe Project - Overview of a proposed Life Cycle Approach for Urban Guided Transport Systems, Transport Research Arena 2012, Book Series: Procedia Social and Behavioral Sciences 48: 3113-3123.
9. **Castella, P.S.; Blanc, I.; Gomez F.M; Ecabert, B.; Wakeman, M.; Manson, JA.; Emery, D.; Han, SH.; Hong, JL.; Jolliet, O.** 2009. Integrating life cycle costs and environmental impacts of composite rail car-bodies for a Korean train, International Journal of Life Cycle Assessment 14(5): 429-442.
10. **Bergerson, J.A.; Lave, LB.** 2005. Should we transport coal, gas, or electricity: Cost, efficiency, and environmental implications, Environmental Science & Technology 39(16): 5905-5910.
11. **Kampf, R.; Stopka, O.; Kubasakova, I.; Zitricky, V**. 2016. Macroeconomic Evaluation of Projects Regarding the Traffic Constructions and Equipment, In World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium 2016, WMCAUS 2016. Book Series: Procedia Engineering 161: 1538-1544.
12. **Ľuptak, V.**; **Gasparik, J.; Chovancova, M.** 2017. Proposal for Evaluating a Connection Quality within Transport Networks, In 18th International Scientific Conference-LOGI 2017. Book Series: MATEC Web of Conferences. Vol. 134. Article No. 00033
13. **Dedik, M**.; **Gasparik, J.; Zahumenska, Z.** 2017. Quality Assessment in the Logistics of Rail Passenger Transport. In 18th International Scientific Conference-LOGI 2017. Book Series: MATEC Web of Conferences. Vol. 134. Article No. 00009
14. **Nedeliakova, E.**; **Panak, M.** 2016. Methodology for Quality Assessment within Transportation Chain. In Proceedings of the 1st International Conference Contemporary Issues in Theory and Practice of Management: CITPM 2016, Czestochawa, Poland, 309-314
15. Cambridge English Dictionary. Cambridge University Press [online cit.: 2018-05-24]. Available from: https://dictionary.cambridge.org/us/dictionary/english/life-cycle-cost
16. **Foltínová, A. et al.**. 2007. Nákladový controlling, [Cost controlling] Publishing SPRINT vfra, Bratislava 2007, 450 p.
17. **Popesko, B.** 2009. Moderní metody řízení nákladů. [Modern methods to management of costs]. Grada Publlisching, a. s. 2009. 233 p.
18. ZSSK. 2004. Maintenance of railway rolling stock, electric and wagons and units, embedded, connecting and source wagons. [online cit.: 2018-02-13]. Available from: https://www.yumpu.com/xx/document/view/46420882/v-25-adra-3-4-ba-hnaca-ch-drahova-1-2-ch-vozidiel-elektricka-1-2-ch-a-motorova-1-2-ch-/14

A selecting the Best Statistical Distribution for Time to Failure the Railway System Components by Using Multi-Criterial Analysis

J. Selech[1], K. Andrzejczak[2]

[1]*Poznan University of Technology, Piotrowo 3, 60-965, Poznan, Poland, E-mail: jaroslaw.selech@put.poznan.pl*
[2]*Poznan University of Technology, Piotrowo 3A, 60-965, Poznan, Poland, E-mail: karol.andrzejczak@put.poznan.pl*

Abstract

The research is focused on identify the time-to-failure of selected component of a complex technical system. The traditional methods of estimating of time-to-failure distribution rely on assumption of predetermined type of distribution of random variable, and then determining the parameters defining this distribution. In the case of field tests, there is generally no complete data concerning mean up time of specific component of the system. Therefore, there is a need to use statistical methods for censored observations. Based on the failure components data recorded in the past, the reliability characteristics can be easily determined. However, there is the problem of optimal identification of the distribution in the context of a specific quality measure of the match. This problem is the subject of research and concerns the determination of mean up time schedules of selected component of rail vehicles. For objects such as intensively used vehicles, these times have been expressed in operational mileage [1]. The results of the analysis were developed in the form of a ranking of the distributions by using the aggregate quality measure of the match as a criterion.
KEY WORDS: *time-to-failure, multi-criterial reliability analysis, censored observation*

1. Introduction

There are various possible probability distributions that can be used to determine reliability data. The reliability assessment of technical systems is most often performed using probability distributions that are commonly used, such as: normal, exponential and Weibull [2, 3]. In this work, apart from the mentioned distributions, other distributions have also been taken into account, which in some cases may be better suited to the data than the most frequently used ones. These are the following distributions: normal, logarithmic-normal, gamma, generalized gamma, logistic, logarithmic-logistic and Gumbel. Estimation of parameters and fitting of probability distributions can be made using analytical methods, but recently numerical methods have been used with dedicated computer packages [4]. The best-fit distribution and estimation of one or more parameters of this distribution (shape, scale, position) requires proper preparation of operational data [4]. Different methods of estimating parameters are used, which include both numerical and graphical methods (least-squares method, Kolmogorov-Smirnov (K-S) test, maximum likelihood estimation, chi-squared test, adjustment of distribution grids, probability plot correlation coefficient (PPCC) [5]. In this work Kolmogorov-Smirnov (K-S) test was used to determine the statistical difference between the expected and obtained result, the Likelihood Value (LKV) test was used to determine the distribution rank for the data under study, and the maximum likelihood method (MLE) was used to estimate the parameters of the selected distribution. The analysis of the reliability of the most damaging and cost-intensive components of railway system, affects not only the level of transport safety, but also provides the theoretical basis for planning reasonable service schedules and reducing the costs of servicing the vehicle fleet [6, 7]. Maintenance activity can be divided into groups: scheduled maintenance and unscheduled maintenance. Scheduled maintenance consists of preventive maintenance, being a planned servicing of vehicles. Unscheduled maintenance is not previously planned but requires prompt attention and must be added to scheduled workloads and usually is being more costly. The main objective of this paper is find the best fitted statistical distribution for time to failure the hydraulic power classified as an unscheduled maintenance.

2. Subject of Research

The research was carried out on the basis of the operational data collected during the operation of the fleet of urban transport vehicles [8]. The scope of the data included five initial years of use of the fleet and two years were covered by the guarantee and the next three years covered by a maintenance agreement. All vehicles were used under similar operating conditions and had similar daily ant total mileage during the survey period. From the operational database, for the assumed period of use, the hydraulic aggregate K140 was selected as one of the most damaging and the most cost-generating components. It is used to generate the required pressure in the brake hydraulic system which is responsible for emergency braking, located on the trailer bogie. Every hydraulic unit consist of an electric hydraulic pump, a tank with hydraulic fluid, overflow valves and brake system controllers [9, 10]. Hydraulic power unit is running on batteries charged by voltage converter. Thanks to the use of battery power supply in case of failure power system, the power supply for braking system is ensured. The most frequent damage of the hydraulic power unit was a leak hydraulic fluid to the engine compartment and damage it. For this reason, reliability tests of the hydraulic power unit have

been the subject of herein research.

3. Reliability Data

As example of long-life data for 5 years of operation for hydraulic power unit is shown in the Table 1, includes exact failure time (in kilometers) and suspension time (in kilometers). Suspension time is right censored data that did not fail by the end of the test.

Table 1

Failure time statistical for hydraulic power unit

Life/(kilometer)	F/S	Life/(kilometer)	F/S	Life/(kilometer)	F/S	Life/(kilometer)	F/S
5 462	F	108 969	F	231 224	F	292 525	F
10 529	F	109 392	S	243 532	S	294 895	S
27 863	F	119 818	F	243 951	F	297 352	S
29 312	S	126 590	F	244 005	S	299 566	F
38 658	S	134 440	F	253 608	F	305 087	S
40 644	S	136 475	S	254 260	F	308 114	S
43 342	F	145 582	F	254 646	S	310 513	S
61 870	F	146 669	F	255 832	S	311 679	S
67 879	S	194 783	F	258 174	F	314 589	S
70 195	S	200 645	F	263 281	S	315 371	S
74 220	S	203 017	F	264 787	S	316 331	S
77 568	S	205 922	S	265 863	S	319 088	S
79 693	S	207 679	S	271 384	S	319 733	S
85 580	S	209 554	F	272 671	S	327 707	S
90 051	S	209 832	F	275 142	F	328 494	S
98 008	F	222 767	S	284 525	S	335 015	S
99 881	S	228 287	F	290 198	S	342 241	S
108 600	F	230 938	S	292 038	S	343 571	S

F – Failure, S – Suspension

4. Selection of the best fitted Distribution Model

ReliaSoft's WEIBULL++ Distribution can provide guidance in selecting a distribution based on statistical tests. The Distribution Wizard uses three factors in order to rank distributions: the Kolmogorov-Smirnov (K-S) test, a normalized correlation coefficient and the likelihood value [4, 11].

Table 2

Rank of distributions for hydraulic power unit

Distribution	AVGOF	AVPLOT	LKV	Ranking
1P-Exponential	0,688302514	4,13	-383,5	8
2P-Exponential	0,554944755	3,98	-382,8	5
Normal	1,74541E-06	1,67	-383,5	4
Lognormal	20,61077272	3,92	-385,5	10
2P-Weibull	12,37451757	3,11	-383,0	7
3P-Weibull	**9,99978E-11**	**1,41**	**-381,9**	**1**
Gamma	8,2573E-07	1,90	-383,2	3
G-Gamma	8,84125E-09	1,50	-381,5	2
Logistic	0,427756752	2,67	-385,2	6
Loglogistic	15,78038795	3,38	-383,8	9
Gumbel	29,77584796	3,57	-388,8	11

In the Table 2, the second column AVGOF contains values obtained using the Kolmogorov-Smirnov (K-S) test. The Kolmogorov-Smirnov (GOF) tests statistical difference between the expected and obtained result. The third column, AVPLOT, provides the results of the second test, which is a normalized correlation coefficient (rho) measures how well the plotted points fit a straight line. The fourth column, LKV, contains the likelihood values, which computes the value of the log-likelihood function given the parameters of the distribution. These three values are then weighted and combined into one overall value, DESV which is given by:

$$\text{DESV} = (\text{AVGOF Rank} \times \text{AVGOF Weight}) + (\text{AVPLOT Rank} \times \text{AVPLOT Weight}) + (\text{LKV Rank} \times \text{LKV Weight}).$$

These values are then weighted and combined into one overall value, DESV, as shown in Table 3. The fifth column contains models distribution ranking which are ranked according to how well they fit the data, with rank 1 being the best fit. Software enables specify different weights depending on whether the parameter estimation method is rank regression or MLE [12].

Table 3

Analysis details

Distribution	AVGOF	AVPLOT	LKV	DESV	Ranking
1P-Exponential	7	11	7	780	8
2P-Exponential	6	10	3	590	5
Normal	4	3	6	440	4
Lognormal	10	9	10	980	10
2P-Weibull	8	6	4	640	7
3P-Weibull	**1**	**1**	**2**	**130**	**1**
Gamma	3	4	5	380	3
G-Gamma	2	2	1	170	2
Logistic	5	5	9	620	6
Loglogistic	9	7	8	830	9
Gumbel	11	8	11	1040	11

Analysis Method uses the maximum likelihood estimation (MLE) for estimating the parameters of the chosen distribution. Rank Method uses the Median Ranks (MED), Confidence bounds Method uses the Fisher Matrix (FM) [4]. In this case, the 3P- Weibull distribution is the suggested model. Next, by calling the program's "plot" command, various graphs were created. Using the Distribution Wizard's recommendations, Weibull distribution with 3 parameters was used for calculations. Their values are: $\beta = 2{,}0833$, $\eta = 392848$, $\gamma = -55320$ and failure rate $\lambda = 0{,}0000047288$/km. Computed graphs are further presented (Figs. 1 and 2).

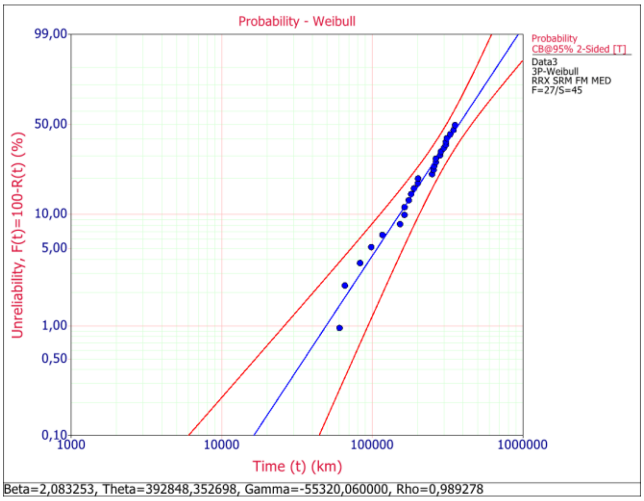


Fig. 1 Weibull probability graphic representation for hydraulic power unit

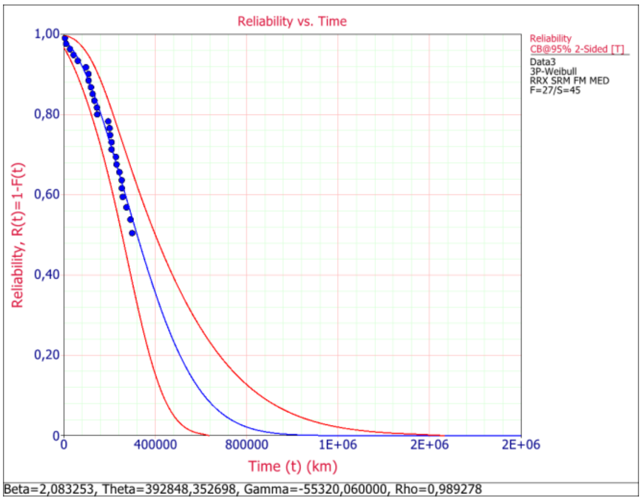


Fig. 2 Weibull reliability graphic representation for hydraulic power unit

The blue line represents the Weibull probability and the red line are two sided 95% confidence bounds. For these analyzed hydraulic power unit, most of the failures occurred between 100 000 and 300 000km. The Reliability vs. Time plot shows the reliability values over time, capturing trends in the product's failure behavior. The mean time to failure MTTF = 341643,3 km.

The pdf plot shows the probability density function of the data over time, allowing you to visualize the distribution of the data set (Fig. 3). On the Fig. 4. the histogram is presented for the data with a range size of 40 000 km. From this histogram, it can be characterizing where the data set fails with respect to its values. This graph illustrates that a relatively high proportion of the data falls between the values of 80 000 km and 160 000 km and next between 200 000 km and 280 000 km.

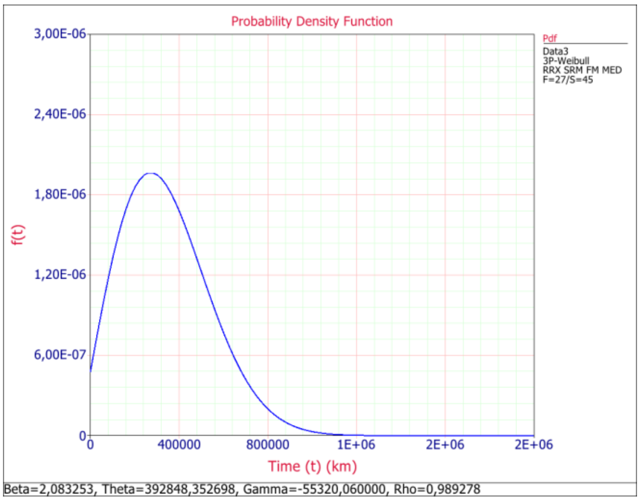


Fig. 3 Probability density plot for hydraulic power unit

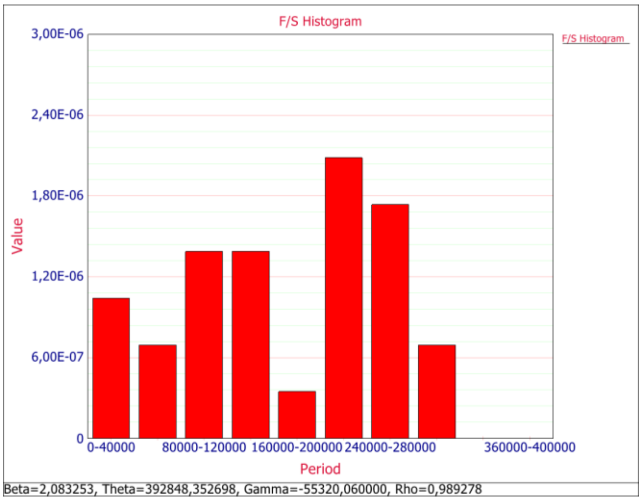


Fig. 4 Histogram for hydraulic power unit data

5. Conclusions

Reliability analysis is mainly used if components using time is known, the mean time to failure is easily predicted based on the above analysis. Estimation of parameter for failure models is necessary for accurate prediction of expected number of components failure over a period of time based on operating conditions for developing cost effective maintenance strategies. This paper is based on collection and analysis of maintenance data over a five years for parameter estimation for probabilistic models predicting hydraulic power unit. There is huge scope for future work in this area for developing decision models related to inspection and replacement selected components of the complex technical object. The analysis result could be as importance reference for establishing fault tree of vehicle transport system. Weibull statistical distribution, among other methods, is helpful in approximating the reliability parameters of an automobile. To improve time efficiency, fast computation is required. In this paper a fast calculation program was presented, developed by Reliasoft, along with a brief description of the methodology.

Acknowledgement

The research work financed with the means of statutory activities PUT 04/43/DSPB/0096 and DS05/51/DSPB/3551.

References

1. **Andrzejczak, K.; Selech, J.** 2017. Quantile analysis of the operating costs of the public transport fleet, Transport Problems 12(3): 103-111, DOI: 10.20858/tp.2017.12.3.10.
2. **Gill, A.** 2017. Optimisation of the technical object maintenance system taking account of risk analysis results, Eksploatacja i Niezawodnosc – Maintenance and Reliability; 19(3): 420-431, http://dx.doi.org/10.17531/ein.2017.3.13.
3. **Hajkowski, J.; Popielarski, P.; Sika, R**. 2017. Prediction of HPDC casting properties made of AlSi9Cu3 alloy, Advances in Manufacturing, SPRINGER, Manufacturing, 621-631, DOI: 10.1007/978-3-319-68619-6_59.
4. https://www.reliasoft.com/Weibull [access: 2018].
5. **Fuc, P.; Rymaniak, L.; Ziolkowski, A**. 2013. The correlation of distribution of PM number emitted under actual conditions of operation by PC and HDV vehicles, WIT Transactions on Ecology and the Environment. WIT Press 174: 207-2019. ISBN: 978-1-84564-718-6.
6. **Dolce, J.E.** 1994. Analytical Fleet Maintenance Management, SAE International, SUA.
7. **Trojanowska, J.; Dostatni, E.** 2017. Application of the theory of constraints for project management, Management and Production Engineering Review 8(3): 87-95, DOI: 10.1515/mper-2017-0031.
8. Research Project “Increase in the efficiency of functioning of public means of transport as a result of implementation of LCC and RAMS concepts in accordance with the IRIS standards based on integrated information technology system” financed by Polish National Center for Research and Development. No. PBS3/B6/30/2015.
9. **Sawczuk, W.** 2016. Application of vibroacoustic diagnostics to evaluation of wear of friction pads rail brake disc, Eksploatacja i Niezawodnosc – Maintenance and Reliability 18(4): 565-571. http://dx.doi.org/10.17531/ein.2016.4.11.
10. **Walus, K.J.** 2017. Driver's Strategy and Braking Distance in Winter, Transport Means 2017: Proceedings of the 21st International Scientific Conference Part 2, p. 505 – 509, ISSN 1822-296 X, e-ISSN 2351-7034.
11. **Andrzejczak, K.; Selech, J.** 2017. Investigating the trends of average costs of corrective maintenance of public transport vehicles, Journal of KONBiN 41: 207-226. DOI 10.1515jok-2017-0011.
12. http://www.weibull.com/hotwire/issue91/relbasics91.htm [access: 2018].

Rolling Stock Stopping for Different Railway Line Speeds and Different Coefficients of Usable Grip: a Case Study

V.Ľupták[1], M. Hlatká[2]

[1]*Institute of Technology and Business in České Budějovice, Okružní 517/10, 370 01 České Budějovice, Czech Republic, E-mail: luptak@mail.vstecb.cz*
[2]*Institute of Technology and Business in České Budějovice, Okružní 517/10, 370 01 České Budějovice, Czech Republic, hlatka@mail.vstecb.cz*

Abstract

In Europe, one of the densest rail networks is in the Czech Republic. There are approximately 9,580 km of railway tracks with almost 9,000 rail crossings. The issue of safety at railroad crossings is present for several decades. The fact is that we can find different types of security devices on the crossings, from the simplest - securing devices is supplemented with the barriers, to the safest ones - extra-level crossing between the road and the railroad. The aim of this article is to analyze the viewing conditions at selected railway crossings with the traffic light securing device and to assess whether these ratios are safe for the passage in case of the traffic light securing device failure or in case of non-compliance with the determined rules by the driver.
KEY WORDS: *Rail crossing, perspective ratios, braking distance, railway line speed, coefficients of usable grip*

1. Introduction

The Czech Republic manages one of the densest rail networks in Europe. There are approximately 9,580 km of railway lines with almost 9,000 rail crossings. In relation to this, the intensity of traffic is increasing, the consequence of which is a growing number of traffic accidents at rail crossings in our country. One of the main causes of these accidents is the insufficiency of perspective ratios in terms of both road vehicle drivers, who are unable to observe the approaching rail vehicle in time, and train drivers, who are unable to stop the rail vehicle before an obstacle at the crossing. The cause of insufficient perspective ratios can be, for example, only vegetation that prevents drivers' adequate vision, the removal of which does not pose a major financial burden for the railroad operator.

2. Possibilities of Avoiding a Colision of Vehicles in Case of the Failure of Light CSD (Crossing Security Device)

Avoiding a collision of vehicles in the event of a failure of light CSD depends in most cases on a proper functioning of warning, which alerts the driver of this failure in time. He or she is then obliged to adjust the operation of the rail vehicle. However, when CSD is in operation, there may be such situations when the failure of warning light is not transmitted to the driver in time or when the driver is entering the rail crossing despite the light CSD warning. In such cases, the possibility of avoiding a collision of vehicles mainly depends on the perspective ratios of both road vehicle drivers and train drivers. These two options will furthermore be discussed in more detail [1, 2].

Possibility of avoiding a colision of vehicles by the train driver

The possibility of avoiding a collision of vehicles at the rail crossing by the train driver depends on the early observation of obstacle on the rail crossing and the stopping of the rail vehicle before this obstacle. Whether the train driver can stop the vehicle in time depends mainly on the driver's perspective ratios and the braking distance of the rail vehicle. In terms of rail crossings the train driver's perspective ratios are determined by the length of his or her clear view of the railway crossing. These ratios are not precisely specified, but the line speed can be adjusted with respect to these ratios at the crossing point.

The stopping distance of rail vehicle is the distance that the rail vehicle covers from the moment when the obstacle is noticed at the rail crossing until the vehicle stops.

The length of this distance is significantly influenced by the low coefficient of usable adhesion on the braking of rail vehicle, which is due to the low rolling resistance during the movement of steel wheel on the rail. The adhesion coefficient values of rail vehicles may vary from 0.05 to 0.15 depending on the condition of track surface. The fundamental influence on adhesion value is the speed of the vehicle and the contact surfaces of the wheel and rail. Apart from usable adhesion, the stopping distance depends on the starting speed of the rail vehicle, gravity acceleration, train driver reaction time, and rise time of braking effect [3].

The calculation of stopping distance of rail vehicle

The stopping distance of the rail vehicle can be calculated by using the following formula:

$$S = s_r \cdot s_b \cdot s_z \,, \tag{1}$$

where S – stopping distance of rail vehicle; s_r – travel distance of rail vehicle within the train driver's reaction time; s_b – travel distance of rail vehicle within the rise time of braking effect; s_z –travel distance of rail vehicle from the rise time of braking effect to the point of stopping the vehicle [4].

It is necessary to calculate the following to fit the 1st equation:

1. Acceleration of rail vehicle on the rise of braking effect (a_z) and afterwards (a_b):

$$a_z = g * \mu \,, \tag{2}$$

where g – gravitational acceleration; μ - coefficient of usable adhesion [4].

2. Speed of rail vehicle after the rise of braking effect (v_z):

$$v_z = v_p - a_b \cdot t_b \,, \tag{3}$$

where v_p – initial speed of rail vehicle; a_b – acceleration of rail vehicle after the rise of braking effect; t_b – time of the rise of braking system [5].

3. Time from the point of rise of braking effect to the point of stopping the vehicle (t_z):

$$t_z = \frac{v_z - v_0}{a_z} \,, \tag{4}$$

where v_z – speed of rail vehicle after the rise of braking effect; a_z – acceleration of rail vehicle on the rise of braking effect [5].

Calculation of individual distances:

$$S_r = v_p \cdot t_r \,; \tag{5}$$

$$S_b = v_p \cdot t_b - \frac{1}{2} \cdot a_b \cdot t_b^2 \,; \tag{6}$$

$$S_z = v_z \cdot t_z - \frac{1}{2} a_z \cdot t_z^2 \,, \tag{7}$$

where t_r – train driver's reaction time; t_z – time from the rise of braking effect to the point of stopping the vehicle.

After completing the default equation to calculate the stopping distance of the rail vehicle we get the following relation:

$$S = v_p \cdot t_p + v_p \cdot t_p - \frac{1}{2} \cdot a_b \cdot t_b^2 + v_z \cdot t_z - \frac{1}{2} a_z \cdot t_z^2 \,. \tag{8}$$

Possibility of avoiding the collision of vehicles by personal vehicle drivers

From this point of view, it is essential whether the perspective ratios are sufficient to allow the slowest vehicle to safely pass through the crossing before the rail vehicle approaches at the line speed. Therefore, it is important to determine the approaching speed of the rail vehicle to the crossing on condition we take into account the viewing distance of the crossing and the speed at which the slowest personal vehicle crosses the railway crossing [6-9].

Calculation of approaching time of rail vehicle

$$T_{ž} = \frac{s_r}{v_t} \,, \tag{9}$$

where s_r – viewing distance of the slowest vehicle; v_t – line speed.

Calculation of crossing time of the slowest vehicle:

$$T_s = \frac{s_p}{v_{nv}} \,, \tag{10}$$

where s_p – distance from the warning device to the external edge of the danger zone of crossing; v_{nv} – speed of the slowest vehicle.

Calculation of stopping distance of rail vehicle

The calculation is based on the procedure to fit into the 1st equation. For illustration, there is a calculation for the case of rail vehicle the speed of which is 100 km / h on a dry track surface (Table 1 and Table 2).

Table 1

Input values

μ – dry surface	μ – wet surface	μ – slippery surface	g (m.s^{-2})	t_r (s)	t_b (s)	v_p (m.s^{-1})
0,15	0,10	0,05	9,81	2	0,5	100

Source: authors

Table 2

Calculations

a_z (m.s^{-2})	a_b (m.s^{-2})	v_z (m.s^{-1})	t_z (s)	S_r (m)	S_b (m)	S_z (m)	S (m)
1,47150	0,73575	27,412	18,63	55,56	13,798	255,32	324,678

Source: authors

The distances for the purpose of stopping the rail vehicle at various speeds and with various coefficients of usable adhesion are given in the following Table 3.

Table 3

Distances for the stopping of rail vehicle

Speed of rail vehicle		Surface adhesion		
km.h^{-1}	m.s^{-1}	dry	wet	Slippery
		0.15	0.10	0.05
10	2.78	8.830	10.163	14.117
20	5.56	22.968	28.236	44.007
30	8.34	42.353	54.186	89.652
40	11.12	66.990	88.014	151.054
50	13.89	96.763	129.556	227.906
60	16.67	131.885	179.112	320.763
80	22.23	217.886	301.859	553.750
100	27.78	324.678	455.811	849.165

Source: authors

The stopping distances, which are highlighted, are at the speeds of 80 and 100 km per hour, because they are the line speeds at the rail crossings, which will be the subject of investigation. They are the maximum speeds, at which rail vehicles can approach the crossings, and their maximum stopping distances. The other speeds mentioned form a base on which the national standard CSN 63 7380 sets the perspective ratios for the slowest vehicle [7].

Rail Crossing P5569

P5569 is a rail crossing with light CSD without train crossing bars, which is located on the 96th km of line No. 196 on the route from České Budějovice to Horní Dvořiště (Table 1). The crossing is located between the train stop Velešín and the railway station Velešín. It is a crossing of the monorail with a purpose road connecting the village of Skřidla with the road III / 15710. The crossing is displayed in the Fig. 1 below [10].

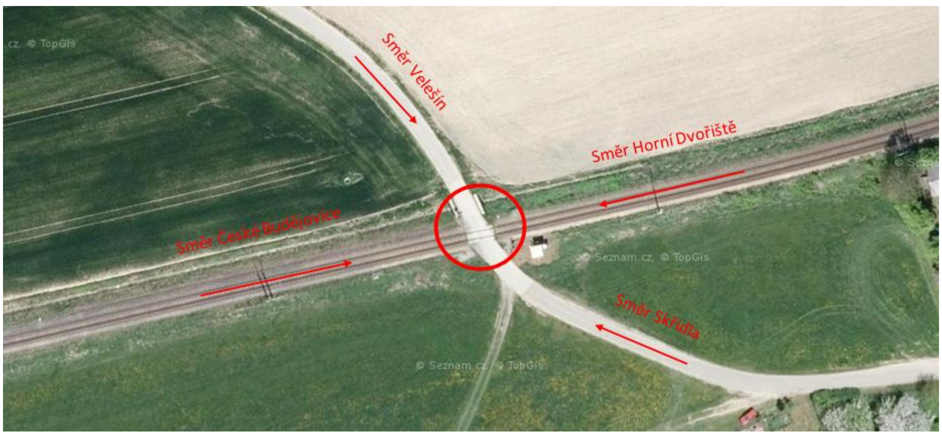


Fig. 1 Level crossing railroad

Table 4

Rail crossing P5569 – basic figures

Crossing No.	P5569
Line	196
Mileage	96 km
Number of tracks	1
Security type	Light CDS without train crossing bars
Number of accidents	0
Type of communications	Purpose
Surface of crossing	Concrete

Source: authors

Approaching the crossing **in the direction of Velešín** the drivers are first informed about the upcoming crossing by the information sign A31a and the additional table indicating the direction of the crossing. However, there is no traffic sign A29 or A30 to alert the driver about the type of railway crossing. Further A31b traffic sign, which would alert the driver about the distance of 160 m to the crossing, is also absent. In contrast, the A31c traffic sign is properly positioned at the distance of 80 m before the crossing. Moreover, the warning sign is also clearly visible from the distance of 80 m. The only exception is the summer season when the safe view of the warning sign is only possible from a distance of 51m. It is due to the plants on the adjacent field that prevent the view in the summer period [11-13].

In the direction of Skřidla there is not either the A31a traffic sign before the crossing, which would alert the driver to the distance of 240 m before the crossing, or the A29 or A30 traffic signs to indicate the type of crossing. There is no other alert of the rail crossing than the A31b traffic sign. The A31c traffic sign follows, from which the driver finally has a good view of the rail crossing. A completely safe view of the warning sign is provided from the distance of 70 meters.

Table 5

Basic parameters of rail crossing P5569

Line speed	100 km.h^{-1}
Length of crossing	5 m
Width of crossing	6 m
Distance of warning signs – direction of Skřidla	5,2 m
Distance of warning signs – direction of Velešín	4,5 m
Distance from the warning sign to the external edge of danger zone – direction of Skřidla	7,7 m
Distance from the warning sign to the external edge of danger zone – direction of Velešín	7 m

Source: authors

The Table 5 indicate that the line speed of the rail vehicles at the crossing point is set at 100 km / h. The width of the rail crossing and the distance of the warning signs are marked in green in the table because they meet the legal requirements. The requirements for the other parameters are not specified by law.

Train driver's perspective ratios at rail crossing P5569

The perspective ratios at the crossing involve the train driver's perspective ratios to the rail crossing and the slowest vehicle driver's perspective ratios to the front of the rail vehicle in both directions of the crossing. The Fig. 2 below shows the train driver's perspective ratios in the direction of Horní Dvořiště [13].

Fig. 2 View from the perspective of the driver´s direction Horní Dvořiště

The picture clearly demonstrates that the train driver‘s viewing distance is only 176 m in the direction of Horní Dvořiště. The vegetation growing in the curve before the rail crossing prevents the train driver from a better view in terms of lenght, as it is shown in the picture.

The train driver’s perspective ratios **in the direction of České Budějovice** are graphically depicted in the following Fig. 3.

Fig. 3 View from the perspective of the driver´s direction České Budějovice

The Fig. 3 shows that the train driver’s viewing length to the crossing is 530 m in the direction of České Budějovice. There are no obstacles in the train driver’s view of the longer distance. It is a flat section of the line without any obstacles. The only limitation is the distance in which the train driver can recognize an obstacle at the crossing [12].

Driver’s perspective ratios at rail crossing

The viewing distance of the slowest vehicle going **in the direction of Velešín** is identical with the train driver’s one. It means that the driver’s viewing distance to the rail vehicle approaching from the direction of Horní Dvořiště is 530 m and the viewing distance to the rail vehicle approaching from the opposite direction of České Budějovice is 176 m [10-14].

Fig. 4 View of the driver direction České Budějovice

As we may notice in the Fig. 4 the vegetation obstructs the view of the line in the curve in the direction of České Budějovice like in the case of the rail vehicle. In the opposite direction, the view is unobstructed and its length only depends on the driver's ability to distinguish the rail vehicles on the line.

In the direction of Skřidla we may notice that the driver’s viewing distance in the direction of Horní Dvořiště is identical with the case of the driver going in the direction of Velešín, e.g. 530 m. The viewing distance in the opposite direction of České Budějovice is only 35 m.

The Fig. 5 shows that the driver has a clear view in the direction of Horní Dvořiště as well and its length only depends on the driver's ability to distinguish the rail vehicles on the line. In the opposite direction, the driver’s view is obstructed by the relay house along the line and therefore the viewing distance is only 35 m in this direction [13].

Fig. 5 View of the driver direction Horní Dvořiště

Possibility of avoiding the collision of vehicles by train driver at rail crossing P5569

The train driver’s possibility of avoiding the collision can be determined on the basis of the data in Table 2, which determines the stopping distance of the rail vehicle for different speeds and the condition of the track surface on the basis of the determined perspective ratios. By comparing the data from Table 2 and the perspective ratios, it will be possible to determine whether the driver is able to stop the rail vehicle before the crossing [14].

Direction of Horní Dvořiště

The train driver‘s possibilities of avoiding the collision of rail vehicle are shown in Table 6.

Table 6

The train driver‘s possibilities of avoiding the collision at rail crossingP5969 – the direction of Horní Dvořiště

Speed of rail vehicle km.h^{-1}	Surface adhesion		
	Dry	Wet	Slippery
	0.15	0.10	0.05
	Stopping of rail vehicle		
10	Yes	Yes	Yes
20	Yes	Yes	Yes
30	Yes	Yes	Yes
40	Yes	Yes	Yes
50	Yes	Yes	No
60	Yes	No	No
80	No	No	No
100	No	No	No

Source: authors

Table 6 shows that if the rail vehicle were travelling at a maximum line speed of 100 km / h, the train driver would not be able to stop it in time before the crossing without paying attention of the condition of the surface of tracks. However, if the security device reported to the driver that the rail crossing was not closed, it would be possible to stop the rail vehicle at all the conditions of track surface, as the vehicle would be moving at a speed of only 10 km / h before the crossing. [12]

Direction of České Budějovice

The train driver‘s possibilities of avoiding the collision of rail vehicle are shown in Table 7.

Table 7

The train driver‘s possibilities of avoiding the collision at rail crossingP5969 – the direction of České Budějovice

Speed of rail vehicle km.h^{-1}	**Surface adhesion**		
	Dry	**Wet**	**Slippery**
	0.15	**0.10**	**0.05**
	Stopping of rail vehicle		
10	Yes	Yes	Yes
20	Yes	Yes	Yes
30	Yes	Yes	Yes
40	Yes	Yes	Yes
50	Yes	Yes	Yes
60	Yes	Yes	Yes
80	Yes	Yes	No
100	Yes	Yes	No

Source: authors

The table clearly shows that if we consider the determined speeds, the rail vehicle would not be able to stop before the crossing only in case the surface of tracks was slippery and the vehicle were travelling at the speed of 80 km/h or at the maximum speed.

Possibility of avoiding the collision of vehicles by personal vehicle driver at rail crossing P5569

The driver’s possibility of avoiding the collision can be determined on the basis of the time for the approaching of the rail vehicle and the time of the crossing of the slowest vehicle. To determine both values, it is necessary to know the viewing length of the slowest vehicle, the line speed at the crossing point, the speed of the slowest vehicle, and the distance from the warning to the external edge of danger zone. All the data are available from the field research.

The evaluation of the road vehicle driver’s possibility of avoiding the collision is in the Table 8 [14].

Table 8

Security of road vehicle drivers‘ perspective ratios at rail crossing P5569 – Table

Direction of vehicle	**View direction**	**S_r**	**T_s**	**$T_ž$**	**Security of viewing length**
Velešín	Horní Dvořiště	530 m	5,228 s	19.080 s	Yes
	České Budějovice	176 m		6.335 s	Yes
Skřidla	Horní Dvořiště	530 m	5,751 s	19.080 s	Yes
	České Budějovice	35 m		1.260 s	No

Source: authors

According to the table, the situation is dangerous when the road vehicle is going in the direction of Skřidla and the railway vehicle is approaching the crossing from the direction of České Budějovice. The perspective ratios are in this case too small to allow the driver of the slowest vehicle to pass safely. In all other cases, the perspective conditions are sufficient and the road vehicle driver can safely pass through the crossing or wait until he observes the approaching rail vehicle to prevent a collision with it.

Summary

The rail crossing P5569 on the line 196 from České Budějovice to Horní Dvořiště was dealt with in an application part of the paper. The basic characteristics and parameters of the crossing were determined and it was found that these parameters correspond to the statutory regulations. In addition, a survey was carried out at the specific crossing point in order to determine the train drivers’ and road drivers’ perspective ratios. The results of this survey were subsequently used in the calculations that assessed whether the perspective ratios were sufficient.

In case of rail crossing P5569, it was found that the perspective ratios are insufficient at the maximum line speed under all the examined conditions in the direction of Horní Dvořiště. It is caused by the vegetation near the track, which obstructs the driver’s clear view of the railway crossing. In the opposite direction of České Budějovice the perspective ratios are insufficient only in case of the slippery surface of tracks and therefore the train driver’s view is not obstructed at all. The only limitation is the distance which is sufficient for recognizing an obstacle at the crossing. It can be assumed that the line speed is too high before the crossing to enable the train driver to prevent a possible collision with an obstacle at the crossing in case of the slippery surface of tracks [14].

The determined train driver’s perspective ratios at the rail crossing P5969 are summarized in the Table 9.

The perspective ratios of road vehicle drivers were found sufficient except in the case when the driver was approaching the crossing from the direction of Velešín at the same time when the rail vehicle was approaching from the direction of České Budějovice. In this case, the road driver's perspective ratios were limited by the relay house located by the crossing. The crossing cannot be considered safe in terms of perspective ratios for this reason.

Table 9

The summary of train driver’s perspective ratios – rail crossing 1P5569

Direction	Line speed	Perspective ratios	Safe perspective ratios		
			Surface of tracks		
			Dry	Wet	Slippery
České Budějovice	100 km.h^{-1}	530 m	324.678 m	455.811 m	849.165 m
Horní Dvořište		176 m			

Source: authors

The determined road driver’s perspective ratios at the rail crossing P5969 are summarized in the Table 10.

Table 10

The summary of road vehicle driver’s perspective ratios – rail crossing 2P5569

Direction of vehicle	Direction of perspective	Perspective ratios	Line speed	Safe perspective ratios
Velešín	Horní Dvořište	530 m	100 km.h^{-1}	145.223 m
	České Budějovice	176 m		
Skřidla	Horní Dvořište	530 m		159.750 m
	České Budějovice	35 m		

Source: authors

3. Conclusion

The aim of the paper is to analyse the possibility of avoiding a collision on the selected rail crossing with the light security device, both by the train driver and by the road vehicle drivers with respect to the perspective ratios at the crossing. The rail crossing with light CSD and its perspective ratios have been analysed. Therefore it was concluded that it cannot be considered safe in terms of perspective ratios in relation to the possibility of avoiding the collision. In determining the train driver’s possibility of avoiding the collision it was found that even unobstructed perspective ratios may not be sufficient at high line speeds and low coefficient of usable adhesion to prevent the collision of a rail vehicle with an obstacle at the rail crossing. In such cases, the distance needed to stop the vehicle is too long to allow the driver to detect the obstacle and to respond by using the brakes of the vehicle. The lower the line speed, and the higher the coefficient of usable adhesion, the greater is the influence of perspective ratios on the train driver's ability to avoid the collision at the rail crossing. However, even in case of high speeds and low coefficient of usable adhesion the importance of perspective ratio is not diminished. Therefore, the sooner the train driver detects the obstacle, the lower the speed of the rail vehicle at the time of the eventual collision and the less fatal the consequences of the collision. Only two cases have been found where the driver's perspective ratios are limited at the crossing. It is the vegetation that obstructs the train driver’s view at the rail crossing P5569 in the direction of Horní Dvořiště.

References

1. **Gasparik, J.; Abramovic, B.; Halas, M.** 2015. New graphical approach to railway infrastructure capacity analysis, Promet-traffic & transportation 27: 283-290.
2. **Gasparik, J.; Zitricky, V.** 2010. A new approach to estimating the occupation time of the railway infrastructure By: TRANSPORT 25: 387-393.
3. **Gašparík, J., et al.** 2016. Mechanika v železničnej doprave, 1. vydanie, Žilina: Žilinská univerzita v Žiline, 278 p., ISBN 978-80-554-1274-0.
4. **Yang, N.-S.; Huang, C.-Y.; Hou, M.-C.** 2013. Inventory-up-level joint replenishment model for re-working materials and new materials, Advanced Materials Research 711: 763-768.
5. **Kampf, R.; Gašparík, J.; Kudláčková, N.** 2012. Application of different forms of transport in relation to the process of transport user value creation, Periodica Polytechnica Transportation Engineering 40(2): 71-75.
6. **Vojtek, M.; Kendra M.; Zitrický, V.; Daniš, J.** 2017. Principles of logistics applied to railway passenger transport In: MATEC Web of Conferences, 8th International Scientific Conference, LOGI 2017, 19th October, Ceske Budejovice; Czech Republic, Vol. 134, Art.
7. **Stopka, O.; Bartuska, L.; Kampf, R.** 2015. Passengers’ evaluation of the integrated transport systems, Nase More 62(3): 153-157.
8. **Kudláč, Š.; Štefancová, V.; Majerčák, J.** 2017. Using the Saaty Method and the FMEA Method for Evaluation of Constraints in Logistics Chain, Procedia Engineering 187: 749-755.
9. **Stopka, O.; Chovancova, M.; Kampf, R.** 2017. Proposal for Streamlining the Railway Infrastructure Capacity on the Specific Track Section in the Context of Establishing an Integrated Transport System, In: MATEC Web of Conferences, 8th International Scientific Conference, LOGI 2017, 19th October, Ceske Budejovice; Czech Republic, Vol. 134, Art.

10. **Chovancova, M.; Klapita, V.** 2017. Modeling the Supply Process Using the Application of Selected Methods of Operational Analysis, Open Engineering 7: 50-54.
11. **Kampf, R.; Lorincova, S.; Hitka, M.; et al.** 2017. Generational Differences in the Perception of Corporate Culture in European Transport Enterprises, Sustainability 9(9).
12. **Bartuska, L.; Stopka, O.; Chovancova, M.; et al.** 2016. Proposal of Optimizing the Transportation Flows of Consignments in the Distribution Center, Conference: 20th International Scientific Conference on Transport Means, Transport Means - Proceedings of the International Conference, 107-111.
13. **Lizbetin, J.; Stopka, O.** 2016. Proposal of a Roundabout Solution within a Particular Traffic Operation, Open Engineering 6: 441-445.
14. **Cejka, J.; Bartuska, L.; Turinska, L.** 2017. Possibilities of Using Transport Terminals in South Bohemian Region, Open Engineering 7: 55-59.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Public Procurement of Innovative Products and Services: New Solutions for Port of Klaipėda

S. Briedienė

Lithuanian Maritime Academy, I. Kanto str. 7, 92123 Klaipėda, Lithuania, E-mail: s.briediene@lajm.lt

Abstract

More than 800 economic agents are directly related to the operations of the port of Klaipėda. The port and the enterprises related to its operations provide more than 58,000 jobs and 6.3% of the Lithuanian Gross domestic product (hereinafter – GDP). Public Procurement in the European Union (hereinafter – EU) accounts for more than 14% of GDP. The European Commission aims to improve Public Procurement practices, promote the demand of innovative goods and services in Europe, and foster the uptake of innovation in the EU. The Government in the Republic of Lithuania wants to improve the management of the institutional capacity, to manage effectively budget funds, to improve Public Procurement for business and public sector. Public Procurement for innovation is about innovative goods and services. It differs from pre-commercial Procurement which supports research and development activities, i.e. before innovative goods or services are ready to be procured.
KEY WORDS: *public procurement, innovative, transparency, management, port of Klaipeda*

1. Introduction

Modernization of the public sector can be noticed in public administration systems of many European countries. With the help of the latest and most advanced New Public Management models, it is aimed to move from the traditional, centralized, hierarchical management to the more efficient, less resources demanding as well as information society formation and service development oriented Contemporary Governance. After the restoration of independence in the Republic of Lithuania, with the launch of free market development, there was a need to regulate the procurements under the public funds, therefore, a number of legal acts regulating the field of Public Procurement were adopted. From the very beginning of the legal regulation of Public Procurement, this procedure of goods, services and works purchase is criticized by the public for inadequately high prices of goods, services and works, that are paid by contracting authority (hereinafter – Recipient of Services) from the taxpayer's money. Another problem is the lack of competition between the suppliers (hereinafter – Provider of Services) regarding the terms of the Contracts and the problem of transparency. Public Procurement is a relatively new practice within the public sector institutions, associated with the ideas of the New Public Management to take over the principles of business management and to adapt them to the activities of public institutions, thus saving the state funds, allocating them more efficiently and fostering the cooperation between the public and private sectors. New Public Management aims to bring the civil servants closer to the managers or officers who apply management principles in performing specific tasks and assignments [5]. Therefore, the perception of the positions of a public servant is important, to what extent he can be apolitical, but at the same time meeting the legal requirements. The presence of the role of manager or administrator is determined by cultural and political context. In continental Europe, civil servants tend to associate their role with the legal aspects, while the Americans perceive themselves as managers [21].

The problems of Public Procurement are not very actively explored in the works of Lithuanian authors. Based on the results of the analysis of catalogues of the libraries of Lithuania it should be noted that researches and practitioners have focused more on the Public Procurement only from 2010, since this year was the starting point for the development of information society in Lithuania and EU Member States, thus at least 50 proc. of Public Procurement are transferred to the electronic space. New Public Management, as a theoretical model and as a practical reform is widely analysed by different authors [3, 6, 12, 13, 18, 25]. The pioneers of the public choice theory have promoted the emergence of researches under the themes of pursuit of personal interests in the political sphere [1, 4]. Exponent of Agency theory has identified the problem of the existence of the interests of the Agent and has prompted the researches within this field [8]. Lithuanian researches and practitioners interested in the New Public Management only briefly mention the need to improve the procedure of Public Procurement in the context of the fight against bureaucracy. N.Leff, S.P.Huntington, P.Beck, M.Maker, A.Antoci and P.L.Sacco et. al. have established the theoretical basis for analysing procedural deviations in Public Procurement in the view of ethical aspect, potential mistakes and incompetence in the Public Procurement process.

Good Governance principles and criteria developed by the experts of World Bank is a tool to improve the public administrations of developing countries, successfully integrating into the New Public Governance and further developing on the basis of this paradigm [26]. In this article it is assumed that Good Governance is not an alternative to the New Public Management and New Public Governance, but is a component part of Public Governance modernization (complement of New Public Management). In the first decade of the XXI century, the Public Procurement, as a research

object has been actively started to be developed in Europe. The Netherlands (the Kingdom of the Netherlands) is one of the EU Member States that implements the principles of the Good Governance the best and which researches have made a major theoretical contribution, reasoning the need of New Public Governance principles introduction into the Public Procurement. C.Harland, J.Telgen, G.Callender and J.Grandia have looked to the Public Procurement through the prism of management science and the possibility to improve this field by using management methods in the management of organizations [10, 11].

Lithuanian authors do not analyse the topic of Public Procurement as Outsourcing in their works. Authors distinguish the features of Manufacturing Outsourcing and Service Outsourcing. Analysing the patterns of Outsourcing human resources evolution, the authors summarize that Outsourcing in the public and private sectors is related with tactical, strategic and reorganization solutions [27, 28]. According others, the management research literature, for more than a decade, analyses the process when organizations some management functions, processes or activities, which were previously carried out within the organization, transfer to the external organizations [2]. Although Outsourcing is based on the ideas of economics and law sciences, the content of Public Procurement, as an external service, has changed. Competition is a key condition for Outsourcing, aimed at ensuring the price and quality of goods, services or works [14]. A new way of providing the public services requires specific skills, related to the management of the Outsourcing and monitoring of this activity performance [16]. Despite that with the help of Outsourcing services, the costs of services have been reduced, the costs of activity performance and valuation have emerged [16, 20].

In the context of New Public Governance, the developing countries of the EU are evolving and develop governance on the basis of Neo-Weberian principles. Neo-Weberian style of governance describes the search of governance problems solutions on the conditions of the global economy crisis [7, 20, 22]. According to W.Drechsler the following Neo-Weberian principles, reflecting the New Public Management can be identified in the process of Public Procurement models search of the developing EU countries: being closer to the citizens and consumer orientation; public discussions and meetings; orientation towards results, evaluating the Public Procurement ex ante, ex post and including monitoring, assessment and forecasting as well as impact assessment of Public Procurement law; professionalism of governance [7]. Researches on the themes of innovation implementation possibilities in Public Procurement can be more widely found in the foreign literature. Public sector organizations are large buyers, thus they can influence the market through demand for innovations, especially as it can be seen in collaboration between different entities of public sector [15]. However, the impact on the market does not always depend on the size of the organization. Often small local authorities are better strategic thinkers than the large ones and have not less knowledge on the marker opportunities formation. Some of authors have analysed and assessed the effectiveness of Public Procurement activities management systems in the local government [19]. Public Procurements play a strategic role in Public Governance (public policy and administration) and can also be used as a necessary tool for the introduction of control and diagnostic systems. In the context of modernization of Public Governance, the importance of Public Procurement as an instrument of local government to support the development of Small and Medium Business in the market is emphasized [9, 17]. Today, Modern Public Governance or Metagovernance require the establishment of measurable indicators system. Performance governance has become a key element in modern society, which also requires measurable organizational and personal effectiveness in both developed and still developing countries [23].

2. Outsourcing in Public Procurement

According below Table 1 port of Klaipėda had thirty-four Public Procurement in 2017, but only twenty-two contracts were signed.

Table 1

List of competitions in the Port of Klaipeda, 2017 year

No.	The subject of Public Procurement	Type	Reg. Number	Status
1.	Repair of underwater part of quays No. 1-157 and removal of navigational obstacles	Simplified open tender	189271	
2.	Purchase of preparation of spatial plan of communications infrastructure development in the territory between Kalnupes, Minijos, Senosios Smilteles and Mariu streets and the Curonian Lagoon of Klaipeda State Seaport Authority	Open tender	189448	Contract signed
3.	Purchase of partial expertise services of Klaipeda State Seaport Authority hydrotechnical constructions	Open tender	189173	
4.	Purchase of database server	Simplified open tender	188893	Contract signed
5.	Purchase of port digital map PORTGIS functionality development	Simplified open tender	188729	Contract signed
6.	Freight and Goods Information System (KIPIS) maintenance and improvement services	Simplified open tender	188331	Contract signed
7.	Technical supervision services of the object „Reconstruction of the objects of infrastructure complex of Klaipeda State Seaport quays No. 10 and No. 11 in Naujoji Uosto str. 23, Klaipeda, capital dredging of the Seaport waters‘ territory and construction of the new access railway“	Open tender	187962	

No.	The subject of Public Procurement	Type	Reg. Number	Status
8.	Construction works of the object „Reconstruction of the objects of infrastructure complex of Klaipeda State Seaport quays No. 10 and No. 11 in Naujoji Uosto str. 23, Klaipeda, capital dredging of the Seaport waters‘ territory and construction of the new access railway“	Open tender	187963	
9.	Upgrading of CCTV (Closed Circuit Television) System	Simplified open tender	187602	Contract signed
10.	Acquisition of supplementary air quality measurement equipment (stationary, 10 sets, with installation and a 3 year period of warranty technical maintenance)	Simplified open tender	186858	Contract signed
11.	Purchase of reconstruction works and outboard four stroke engine for boat „Zunda“	Simplified open tender	186944	Contract signed
12.	Maintenance dredging works of Klaipeda State Seaport waters‘ territory alongside the quays	Simplified open tender	186951	Contract signed
13.	Acquisition of anchor	Simplified open tender	186856	Contract signed
14.	Repair of underwater part of quays No. 1-157 and removal of navigational obstacles	Simplified open tender	186624	
15.	Object „Reconstruction of existing railways and construction of new railways in Naujoji Uosto str. 23, Klaipeda, Klaipeda Municipality”	Open tender	186017	Contract signed
16.	Preparation of technical design and supervision of project implementation services of the object „Capital repair of Klaipeda State Seaport quays No. 77 and 78 in Nemuno str. 8, Klaipeda”	Open tender	186016	
17.	Execution of monitoring services of Baltic av. - Minijos str. cross-road transport flows and preparation of the 5 year long- term forecast of transport flows	Simplified open tender	185903	
18.	Development of an information system of port for control and risk assesment of dangerous goods and hazardous materials	Simplified open tender	185846	Contract signed
19.	Creation, preparation and production of advertising and clerical accessories	Simplified open tender	185755	
20.	Purchase of navigation buoys	Simplified open tender	185359	Contract signed
21.	Repair of underwater part of quays No. 1-157 and removal of navigational obstacles	Simplified open tender	185271	
22.	Maintenance dredging works of Klaipeda State Seaport waters’ territory seabed alongside the Seaport quays	Simplified open tender	185270	
23.	Purchase of inflatable diving boat with an outboard four stroke engine	Simplified open tender	185192	Contract signed
24.	Repair of pilot boat „Gelmė”	Simplified open tender	185113	Contract signed
25.	Purchase of construction and capital dredging works of the object „Reconstruction of quay No. 105 and a section of quay No. 106 of Klaipeda State Seaport Authority	Open tender	184443	Contract signed
26.	Technical supervision of construction works of the object „New construction of railways and reconstruction of railway No. 15 (unique number No. 4400-3031-3521) in Nemuno str. Klaipeda, Klaipeda municipality	Simplified open tender	184412	Contract signed
27.	Construction works of the object „New construction of railways and reconstruction of railway No. 15 (unique number 4400-3031-3521) in Klaipeda Nemuno str”	Simplified open tender	184339	Contract signed
28.	Modernization of PBX system	Simplified open tender	184322	Contract signed
29.	Acquisition of power supply batteries for buoy equipment	Simplified open tender	184323	Contract signed
30.	Services of preparation of technical design and supervision of implementation of the construction design of the object „Capital repair of quay No. 54 in Pilies str., Klaipeda”	Simplified open tender	183907	Contract signed
31.	Technical supervision of construction works of the objects „Dock pit excavation, construction of the new dock anchorage system and reconstruction of quays No. 137 A, 138 A and 139 (part) with railway construction, Minijos str. 180, LT-93269, Klaipeda” and „Demolition of quays No. 137 and No. 138, Minijos str. 180, Klaipeda”	Open tender	183588	
32.	Purchase of special inspection works of Klaipeda State Seaport hydrotechnical constructions	Open tender	183556	
33.	Purchase of consumption items for multifunction office printers and computer equipment repair works	Simplified open tender	182871	Contract signed
34.	Purchase of diesel fuel for ships of SE Klaipeda State Seaport Authority	Simplified open tender	182674	Contract signed

Public Procurement Outsourcing as a process can be defined as a whole of various actions, necessary to Recipient of Services, in order to receive needed goods, services and works from the Provider of Services. Developing the ideas in the context of New Public Management evolution to New Public Governance, together introducing the princi-

ples of Good Governance, the use of new management strategies can help the Recipients of Services to create the added value and save the state budget funds. The aim of Public Procurement Outsourcing Process Governance model (Fig. 1) – to ensure the improvement of Public Procurement process oriented to existing market players and their needs. The aim of the Recipient of Services manager – to develop a continuously improving and effective Public Procurement organization and internal control system. The following risks can be distinguished in the process of Public Procurement Outsourcing till the identification of the need for purchase:

1. Inadequate identification of needs, planning and budgeting:

a) incorrectly defined needs, poor planning of procurement;

b) failure to plan a real budget;

c) incompatibility of Public Procurement with the general investment decision-making in organization;

d) interference of unrelated high-level officials in the procurements decision-making;

e) informal, unlawful agreements with potential Providers of Services regarding award of the Contract.

2. Determination of non-objective and non-conforming the situation requirements:

a) inequity, adaptation to a specific (one) Provider of Services;

b) unjustified and unclear assessment of effectiveness criteria;

c) unfair and unclear criteria of Providers of Services selection;

d) alleged licensing of Providers of Services, fraudulent qualification (e.g. applied dubious tests, issued fraudulent certificates of activity quality assurance).

3. Selection of wrong purchase method:

a) lack of Public Procurement strategy, which leads to generation of unnecessary administrative costs:

b) abuse of non-competence procedures, applying law exceptions, when: procurements are subdivided into smaller ones; special rush; exceptions based on technical aspects or exclusive rights; lack of inspection of existing Contracts' changes;

4. Insufficient time to submit Tenders:

a) inconsistently applied timeframe for all service providers (e.g., when information is leaked to one participant);

b) insufficient time to grant the same conditions to all Providers of Services participating in the public tender.

5. Disclosure of publicly non-announced (confidential, sensitive) information:

a) lack of competition between the Providers of Services;

b) submission of tenders upon the conclusions of a prohibited agreement, increase in the value of the bid.

6. Probability of occurrence of conflicts of interest, when the evaluation and approval of proposals creates preconditions for bias and corruption:

a) the risk of personal interest, publicity of Providers of Services, gifts, abuse of effective "Four-Eyes" principle;

b) lack of clear distinction of evaluation criteria for determining the winner, doubts about the reality of Impartiality Declaration and Confidentiality Declaration.

7. Insufficient supervision of civil servants and insufficient separation of financial responsibilities, especial of payments. Which causes:

a) incorrect accounting and costs allocation or migration of costs between the contracts;

b) late payments of Invoices, execution of delays in payments in order to review the prices and thus increasing the economic value of the Contract;

c) false or duplicated issue of Invoices for the non-delivered goods, or non-provided services, as well as executed uncontrolled interim payments [24].

It is necessary to implement the following elements of Contemporary Governance at individual stages of the Public Procurement process, emphasizing the intervention of the head of the persons who controls the Public Procurement and Public Procurement Contracts and Recipient of Services as well as the responsible participation:

- Need – department of Recipient of Services carries out a market research, prepares the justification for the need to purchase, completes the procurement list;
- Procurement Planning – the Planner prepares, delivers for coordination and approval the Procurement Plan and its changes, completes Procurement Plan preparation and changes inspection lists;
- Initiation – department of Recipient of Services carries out a more detailed market research, completes, delivers for coordination and approval the Application;
- Procurement execution – commission or procurement organizer prepares, delivers for coordination and approval procurement documents; procurement organizer executes Small Value Public Procurement within the organization of Recipient of Services following the set procedure ant at the same registers the procurements in a dedicated book, completes Small Value Public Procurement certificate; commission evaluates the proposals and makes a decision on the winners, prepares the Contract draft, preparation inspection list, procurement procedure inspection lists, examines the received claims;
- Contract signing – commission or procurement organizer prepares the Contract draft, delivers it for coordination, supplies the Contract for signing or propose to terminate the procurement procedures;
- Monitoring and control – department of Recipient of Services coordinates (organizes) the execution of the Contract, evaluates its results, makes proposals for extension, termination, changes, prepares the draft of Contract extension/termination, completes the Procurement Contract changes inspection list.

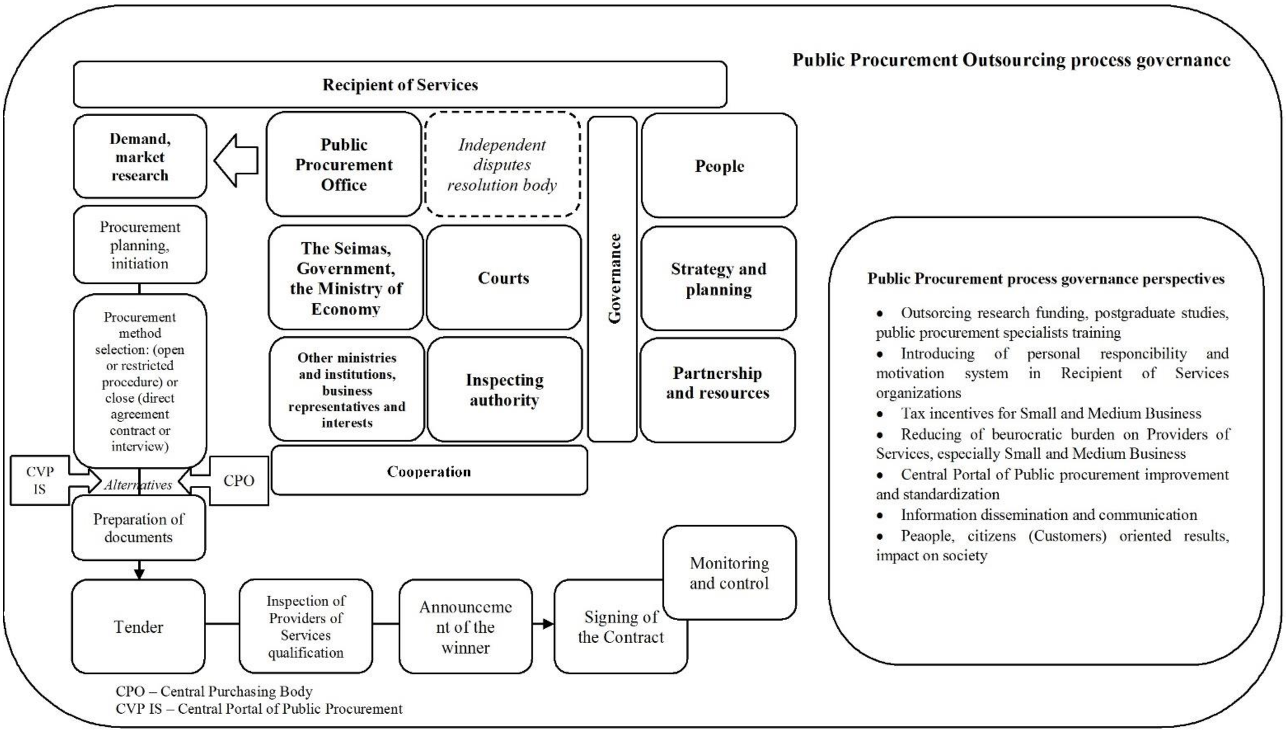


Fig. 1 Suggested model of Public Procurement of Innovative Products and Services for the Port of Klaipeda

Summarizing, it can be states that effective Public Procurement Outsourcing process in Lithuania needs objective political leadership and strong coordination at the governmental level. The model and recommendations have been formulated taking into account the continuity of Public Procurement Process Governance as well as the use of new instruments improving the current Public Procurement Process Governance.

3. Conclusions

Evolving into a New Public Governance, the New Public Management relates the Public Procurement of Innovative Products and Services to self-organizing procedural governance, mainly focusing on the process itself, which includes the Providers of Services and not only Recipients of Services, public institutions and organizations, as well as subjects of Public Procurement policy. Although the scientific literature does not provide for general definition and set of criteria of Public Governance, but the Good Governance principles (accountability, rule of law, availability of information of government actions and its transparency) elaborated by the World Bank are the basis for improvement of Public Procurement of Innovative Products and Services. Summarizing the results of the research, the set of criteria of Public Procurement of Innovative Products and Services can be distinguished: responsibility based on assessment and motivation; cooperation as an objective of the common result; development of innovations as a tool to keep up with the changes and adapt to the environment; the rule of law as a helping tool to achieve the most economic efficient result and market analysis as a successful interconnection of Recipients of Services and Providers of Services and a foundation of a public interest.

References

1. **Arrow, K.J.** 1963. Social Choice and Individual Values. New York, London, Sydney [online cit.: 2013-12-01]. Available from: http://cowles.econ.yale.edu/P/cm/m12-2/.
2. **Bakanauskienė, I.; Brasaitė, D.** 2011. Personalo valdymo funkcijos iškeldinimo galimybės Lietuvoje, Organizacijų vadyba: sisteminiai tyrimai 57: 21-31. (in Lithuanian).
3. **Bouckaert, G.** 2006. Modernising Government: The Way Forward – a Comment. International Review of Administrative Sciences 72(3): 327-332.
4. **Buchanan, J.; Tullock, G.** 1958. The Calculus of Consent: Logical Foundations of Constitutional Democracy [online cit.: 2013-12-01]. Available from: http://www.econlib.org/library/Buchanan/buchCv3.html.
5. **Christensen, T.; Laegreid, P.** 2010. Ashgate Research Companion to the New Public Management. Farnham: Ashgate.
6. **Denhardt, R.B.; deLeon, L.** 2000. The Political Theory of Reinvention. Public Administration Review 60(2): 89-97.
7. **Drechsler, W.** 2005. The Re-Emergence of „Weberian“ Public Administration After the Fall of New Public Management: The Central and Eastern European Perspective, Halduskultuur 6: 94-108.

8. **Eisenhardt, K.M.** 1989. Agency Theory: An Assessment and Review, Academy of Management Review 14(1): 57-74.
9. **Erridge, A.** 2007. Public Procurement, Public Value and the Northern Ireland Unemployment Pilot Project, Public Administration 85(4):1023-1043.
10. **Grandia, J.** 2015. Implementing Sustainable Public Procurement. An Organisational Change Perspective. Thesis to Obtain the Degree of Doctor from the Erasmus University Rotterdam by Command of the Rector Magnificus, the Netherlands [online cit.: 2016-09-23]. Available from: http://download.e-pubs.nl/234/j.grandia.pdf.
11. **Harland, C.; Telgen, J.; Callender, G.** 2012. International Research Study of Public Procurement. C.Harland, G.Nassimbeni, E.Schneller (Ed.). Handbook of Strategic Supply Management. London: Sage, 374-401.
12. **Hood, Ch.** 1991. A Public Management for All Seasons? Public Administration 69(1): 3-19.
13. **Hood, Ch.** 1995. The „New Public Management“ in the 1980s: Variations on a Theme, Accounting, Organizations and Society 20(2-3): 93-109.
14. **Kettl, D.F.** 2010. Governance, Contract Management and Public Management. St.Osborne (Ed.). The New Public Governance. London: Routledge, 239-254.
15. **Knutsson, H.; Thomasson, A.** 2014. Innovation in the Public Procurement Process: A Study of the Creation of Innovation-Friendly Public Procurement, Public Management Review 16(2): 242-255.
16. **Lane, J.E.** 2000. New Public Management. London: Routledge.
17. **Loader, K.** 2016. Is Local Authority Procurement Supporting SMEs? An Analysis of Practice in English Local Authorities, Local Government Studies 42(3): 464-484.
18. **Osborne, D.; Gaebler, T.** 1992. Reinventing Government: How the Entrepreneurial Spirit is Transforming the Public Sector. New York: Addison-Wesley.
19. **Patrucco, A.S.; Luzzini, D.; Ronchi, S.** 2016. Evaluating the Effectiveness of Public Procurement Performance Management Systems in Local Governments, Local Government Studies 42(3): 464-484.
20. **Peters, B.G.** 2009. Still the Century of Bureaucracy? The Roles of Public Servants, Viešoji politika ir administravimas 30: 7-22.
21. **Peters, B.G.** 2015. Įvadas. Viešojo administravimo teorijos. J.Urbanovič, V.Smalskys (Sud.). Vilnius: Mykolo Romerio universitetas, 8-14. (in Lithuanian).
22. **Pollitt, Ch.; Bouckaert, G.** 2004. Public Management Reform: A Comparative Analysis. 2nd edn. Oxford: University Press.
23. **Rhodes, M.L.; Biondi, L.; Gomes, R.; Melo, A.I.; Ohemeng, F.; Perez-Lopez, G.; Rossi, A.; Sutiyono, W.; Sarrico, C.S.** 2012. Current State of Public Sector Performance Management in Seven Selected Countries. International Journal of Productivity and Performance Management 61(3):235-271.
24. **Seikalis, T.** 2016. Seminaras „Viešieji pirkimai: ką privalo žinoti specialistas“. Dorevi, 2016 m. rugsėjo 9 d., Klaipėda. (in Lithuanian).
25. **Schedler, K.; Proeller, I.** 2002. The New Public Management: a Perspective from Mainland Europe. K.Mclaughlin, St.Osborne, E.Ferlie (Ed.). New Public Management: Current Trends and Future Prospects. London: Routledge.
26. **Urbanovič, J.; Bileišis, M.; Stankevič, B.; Stasiukynas, A.** 2015. Viešojo valdymo reformų koncepcijų turinys ir evoliucija. Viešojo administravimo teorijos. J.Urbanovič, V.Smalskys (Sud.). Vilnius: Mykolo Romerio universitetas, 203-246. (in Lithuanian).
27. **Žitkienė, R.; Blusytė, U.** 2014. Paslaugų įmonių žmgiškųjų išteklių užsakomosios veiklos valdymo modelis. 4th International Scientific Conference – „Whither Our Economies” November 12-13, 2014 Proceedings, 173-185. (in Lithuanian).
28. **Žitkienė, R.; Blusytė, U.** 2015. The Management Model for Human-Resource Outsourcing Among Service Companies. Intellectual Economics 9(1): 80-89.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Economic Aspects of the Risk Impact on the Fuel Distribution Enterprises

K. Kampová[1], K. Mäkká[2]

[1]*University of Žilina, Univerzitna 8215/1, 010 26 Žilina, Slovakia, E-mail: Katarina.Kampova@fbi.uniza.sk*
[2]*University of Žilina, Univerzitna 8215/1, 010 26 Žilina, Slovakia, E-mail: Katarina.Makka@fbi.uniza.sk*

Abstract

The paper deals with the prevention of accidents in fuel distribution enterprises, which are not subjected to the act on the Prevention of Major Industrial Accidents in the Slovak Republic and the SEVESO Directive. The article describes expected effects and impacts on the population in the event of an emergency occurring in connection with the service of the filling station. Using the CBA method, it refers to the economic benefits associated with the implementation of preventive measures based on conducting a voluntary risk assessment of these enterprises.
KEY WORDS: *cost benefit analysis, risk assessment, filling station, emergency scenario, preventative measures.*

1. Introduction

Nowadays, security threats related to the storage and transport of dangerous substances, which create considerable potential for the occurrence of industrial accidents caused by deliberate or unintentional human behavior or system failure, need to be addressed. The impacts of such failures or acts in most cases have far-reaching consequences for human health, nature and property. An example may be the recent accident in the Czech Republic, where 6 people died in the Kralupy nad Vltavou explosion.

The European Union is creating a number of directives to prevent such situations. One of these instruments is the SEVESO Directive, which each Member State must implement in its legislation. This Directive establishes a system of categorization of undertakings on the basis of the quantity of dangerous substance held. Another instrument is, for example, the European Union Directive on the Prevention, Preparation and Response to Terrorist Attacks on Elements of Critical Infrastructure, the European Parliament's II. the degree of petrol vapor recovery when pumping fuels into motor vehicles at service stationsBased on enterprice categorization governed by EU directives, a risk assessment for the enterprise meeting the criteria and the subsequent adoption of measures is regulated in a direc-tive manner. However, when selecting precautionary measures, there is no generally valid procedure pointing to the choice of one particular measure or draft measure.

Assessing the safety risks of such entities is a systematic approach, the outcome of which is the different risk scenarios [2]. Consequently, the process of planning and taking action follows the process. In this article, we would like to point out the possibilities of using Cost-benefit analysis as a tool for selecting optimal options for security measures to provide assistance to one or more of the criteria for choosing new or additional security measures. This approach will be applied to the selected service station. The filling stations in view of the SEVESO directive belong to the so-called of non-classified enterprises that do not have directives to conduct a risk assessment. Therefore, we wanted to point out in the article how to use the CBA method as an effective tool presenting the costs and benefits of choosing preventative measures.

2. Cost-Benefit Analysis as a Tool Forchoosing an Optimal Choice of Security Measures

CBA analysis is a methodical approach that gradually responds to the basic question: What does the implementation of the project bring to and to whom does it take? The effects of the action thus defined are gradually aggregated, transferred to cash flows and included in the calculation of decisive indicators that can determine whether or not the project is a contributing factor to the company. When comparing two or more projects, then they allow calculated pointers to determine their order, or to prioritize one project before the other. In general, cost-benefit analyzes are compiled from two basic parts, namely financial and economic analysis. Financial analysis works with financial costs and income. Its main objective is to evaluate the project in terms of financial efficiency for the investor. The economic analysis also takes account of all the direct and indirect benefits of all the actors concerned. A key factor is not a profit but a socio-economic impact that is an economic recovery [3]. The overall cost-benefit analysis of the safety framework related to the assessment process and the risk management process is illustrated in Fig. 1.

The cost-benefit analysis of security management is based on the risk assessment process. Under the Likelihood of Incident step, the different occurrences of the incidents in the selected subject are identified in detail, analyzed and evaluated. Based on the probability of incidents described by the scenarios, it is possible to subsequently propose preventive measures for a specific scenario of the incident. The Effectiveness process results in assessing the effectiveness of the proposed precautionary option for a particular incident scenario. This means assessing the risk of an incident occurring before and after the adoption of the precautionary measures. This step is significant in terms of cost estimates and, in particular, the benefits of implementing a preventive measure. The Costs process is designed to

evaluate the cost of each risk mitigation measure within the variation. These costs include, for example, the direct costs of implementing the preventive measure and the indirect costs associated with its use. The benefit assessment process is to define the costs derived from the selected incident scenario [4]. Incidental losses can include death, environmental damage, property loss. The losses defined in this way are converted into cash flows and represent the benefits we gain when implementing the measures. The final step of the CBA method is to calculate the net benefit or net present status for each relevant scenario and specifically the proposed precautionary measures.

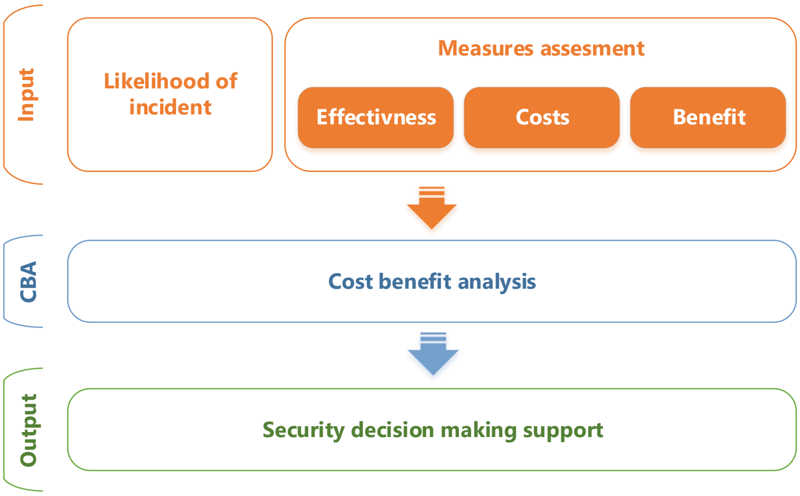
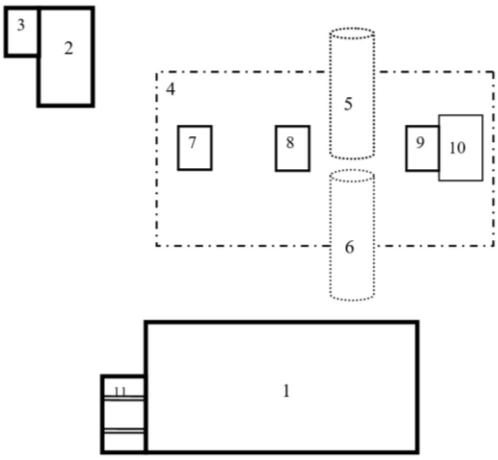


Fig.1 Cost Benefit analysis process within the security framework

3. Case Study of Using CBA Analysis

Filling stations belong to the group as an unclassified source of risk, ie they do not fall under the SEVESO Directive but because of their location near the residential area, the relatively large quantities of fuels represent a source of risk that needs to be assessed from the point of view of its safety. Within the article, with a view to better highlighting the possibilities of using cost-benefit analysis, we will focus on one selected filling station.

In the filling station (Fig. 2), these possibilities of emergency spills of fuels from the storage and handling areas were identified as significant [5]. The real cases where fuel leakage may occur are shown in Table 1.



Object	Object name
1	Service Object
2	Car wash
3	Sewage treatment
4	Handling area
5,6	Storage tank
7,8,9	Fuel dispenser
10	Racking station
11	Warehouse of heating oil

Fig. 2 Filling station objects

The selected filling station contains hazardous substances such as motor fuels classified as dangerous according to the international regulations for the transport of dangerous substances of ADR in the 3rd class of hazards - flammable liquids [6] (Table 1).

Table 1

Dangerous substances present in the filling station

Dangerous substance	Device	Quantity [t]	Threshold value * [t]
diesel fuel	Storage tank	39,1	2 500
	Tank	39,1	
petrol "Natural 95"	Storage tank	36,8	2 500
	Tank	36,8	

* - specified in Annex no. 1 of Act 261/2002 Coll [1]

In the filling station, these possibilities of emergency spills of fuels from the storage and handling areas were identified as significant. The real cases where fuel leakage may occur are shown in Table 2.

Table 2

Emergency scenarios

Emergency scenario	Type of leakage	Priority of incident	Cause of leakage
1. leakage of fuel during bottling	a single leakage of the entire quantity of tank	1	damage to the shell of the tank
	continuous leakage of bottled fuel	2	bursting of the hose, or incorrect fitting on the connections with the boiler or tank, filling of the tanks, deliberate damage
2. leakage of fuel from storage tanks	Continuous	2	leakage of storage tanks
3. leakage of fuel from the connecting pipe	Continuous	3	cracking or leakage of the transport piping
4. leakage of fuel from fuel tank dispensers	Continuous	4	damage to the dispenser stand or dispensers when fueling the fuel in customer vehicles

The priorities of individual scenarios were determined from the established emergency scenarios based on their index evaluation. The first priority of the solution at the filling station is the gasoline tank when it is pumped into storage tanks

An unlikely accident scenario of an extraordinary event under standard operating conditions and in a quieter state is the initiation and subsequent fire or the explosion of underground storage tanks. Damage to underground fuel tanks with fuel is real only in the event of aircraft crashing into the area of filling station and under war conditions [7]. From established emergency scenarios, based on their index rating, a significant source of risk in the filling station is, in particular, a gasoline tank when it is pumped into storage tanks [5].

3.1. Estimation of Population Presence

The filling station is located on an area of 1500 m^2 and represents an area where people present in the filling station object (employees, customers) can move freely. At an estimated population density in the industrial-commercial zone, 80 people / ha is the number of persons on the area of filling station (about 0.15 ha x 80 people / ha) of 12 people. The presence of the population in the filling station object varies within 24 hours, it is different in day and night. For the case study case, the daily time is considered. The number of fatally wounded in the filling station during the day when the petrol was fired was set at 8 people (Table 3) [5].

Table 3

Social risk

Emergency scenario	The total frequency of the	Estimate of fatal	Social risk <0,10>
1. leakage of fuel during bottling	1a) $4*10^{-6}$. year^{-1}	8	Acceptable
	1b) $5*10^{-8}$. year^{-1}	8	Acceptable

3.2. Proposals to Improve the Population Protection System Around the Filling Station

On the basis of the analysis of the consequences of extraordinary events following the emergency scenarios and the estimation of the social risk, it can be stated that filling station activities create preconditions for threats to the persons located in filling station or in its close proximity. The risk of a person's emergency in case of an emergency is the highest during the pumping of the fuel from the tank to the storage tanks. Based on the modeling of emergency scenarios and the consequences associated with them, we set out proposals, namely:

1.We recommend that you carry out risk management for those facilities that have been identified as significant for a major accident. The risk management system includes:

- Major accident risk assessment - Perform every 5 years or in the event of significant changes in the safety of the plant's operation.
- Organization and staff - to carry out regular trainings, to establish responsibilities and powers for individual employees in the field of accident prevention.
- Emergency planning - emergency plan processing and exercise (intervention training).
- Control - monitoring the effectiveness of the risk management system for the continuous improvement process.

2.We propose to establish an "Autonomous Warning System" to alert customers, drivers, and population to the threat zone. From the point of view of employee protection, it is essential to obtain special means of individual protection to protect the respiratory tract and the surface of the body (intervention suit) in two pieces in case of a large extent of an extraordinary event. If an extraordinary event of a lesser extent occurs, which may endanger the health of employees or if it is not possible to use an intervention suit due to time, it is possible to use masks with special filters for health protection.

3.The emergency plan of the filling station is designed only for cases of emergency water hazard, there is no elaborated procedure for dealing with and elimination of an emergency such as the release of the fuel, their ignition, the onset of the fire and the explosion. The safety measures of filling station indicate that there is a risk of fire in the event of a leakage of fuel, a strict smoking ban, strict safety, informing Fire and Rescue Service, alert employees and customers and, until the arrival of Fire and Rescue Service, take part in rescue and firefighting measures without endangering their own person. The fire on filling station during the bottling of the fuel is a danger to its surroundings, because it threatens to expand it to surrounding objects. Only an immediate and correct response to a fire can prevent it from spreading and prevent losses on life and property. To do this, it is necessary to perform simulation training aimed at practicing the intervention in the event of such an extraordinary event.

3.3. Cost Benefit Analysist Within Expression of Losses in the Event of an Extraordinary Event in the Filling Station

Based on the described case study, the various existing models can evaluate the costs and benefits associated with implementing the proposed measures at the filling station that are directly related to the selected emergency scenario at the filling station. In the following tables, the opportunity to use the CBA analysis method presents the costs associated with the implementation of the proposed measures for a period of 5 years after their introduction (Table 4).

Table 4

Costs of implementing proposals

Cost of preventive measures	Together	Present value	2019	2020	2021	2022	2023
Direct costs of preventive actions	27 000€	25 064€	21 000€	1 500€	1 500€	1 500€	1 500€
Maintenance costs	2 000€	1 687€	0€	500€	500€	500€	500€
Operating costs together	29 000€	27 146€	21 000€	2 000€	2000€	2000€	2000€
Together	58 000€	53 897€	-	-	-	-	-

The benefits linked to the implementation of the proposed measures can be summarized in the following table. Within this table, the shadow estimated costs associated with the implementation of the selected emergency event scenario. The cost of human life being calculated on the basis of a study carried out at the 1st Faculty of Medicine of the Charles University in Prague [8]. The cost of the number of injured people is based on the expected length of treatment and the associated treatment costs. The cost of the property was calculated on the basis of an estimate of the damage to the service station and the surrounding buildings, based on the simulation of the consequences of the emergency scenario Leakage of fuel during bottling (Table 5) [9].

Table 5

Estimation of the consequences of an emergency scenario

Estimation of the consequences of an emergency scenario - leakage of fuel during bottling	
Damage to life	8 dead 2 927 600 € [1].
Explosion of persons outside the building	4 people injured
Environmental damage (removal of leaked fuel from soil)	4 700 €
Property damage (in the case of explosion, damage to objects of the filling station)	1 500 000 €

On the basis of the quantified financial flows related to the cost of implementing the proposed measures and the benefits of the non-realization of the foreseen facts, it is possible to confirm that the investment in the proposed measures is effective, as evidenced by the analysis of CBA. It should be emphasized that there is a reduction in the risk associated with the scenario in the implementation of the measures, which means that the reduced risks should be acceptable in terms both of a community-wide but also of an operator's point of view.

4. Conclusions

In the article, we pointed out the possibilities of using the cost-benefit analysis method. Based on this method, it is possible to present the benefits of introducing additional or complete new measures within, for example, SEVESO's unclassified elements, but also other enterprises that create sources of danger. An entity that creates such an analysis gets a picture of the possible financial costs incurred in implementing the threat scenarios that affect it and also leads to a positive attitude towards the cost of the security measures. It is important to note that the CBA method hides a number of uncertainties about the calculations based on shadow models, but with certain procedures and methods, it is possible to work successfully with this uncertainty.

It should be emphasized that the cost of risk assessment may return, because it is better to prevent a major accident as a crash liquidity and restore the original state. It is preferable not only for safety but also for economic aspects. This can be expressed by a qualified estimate that the funds spent on prevention compared to the funds spent on liquidation are approximately seven times lower.

Acknowledgements

This work has been supported by VEGA grant No. 1/0240/15 named „Process model of critical infrastructure safety and protection in the transport sector.

References

1. Act No. 261/2002 Coll. Of the Ministry of the Environment on Prevention of Major Industrial Accidents, as amended.
2. **Kampová, K.; Mäkká, K**. 2013. Human security management. In: Security management and society. Brno: Univerzita obrany, 2013. ISBN 978-80-7231-928-2.
3. **Kampová, K.; Loveček, T**. 2011. Uncertainty in quantitative analysis of risks impacting human security in relation to environmental threats. In: Understanding and managing threats to the environment in South Eastern Europe. - Dordrecht: Springer, 2011. ISBN 978-94-007-0610-1. 249-363 p.
4. **Zvaríková, K.** 2011. Moderný rámec analýzy rizika . In: Globalizácia a jej sociálno-ekonomické dôsledky '11 [elektronický zdroj]: zborník z medzinárodnej vedeckej konferencie : Rajecké Teplice 4.-5. október 2011. ISSN 1336-5878. 643-646 p.
5. **Zvaríková, K.** 2008. Algoritmus hodnotenia nezaradených zdrojov rizík, dissertation thesis, University of Žilina. 146 p.
6. Emergency plan of filling station Slovnaft, 2017.
7. **Leitner, B.** 2017**.** A general model for railway systems risk assessment with the use of railway accident scenarios analysis. Procedia Engineering. ISSN 1877-7058. - Vol. 187, online, p. 150-159.
8. Českí odborníci stanovili hodnotu života. Zdravý človek má cenu 365-tisíc eur! [online cit.: 2018-06-08]. Available from: http://www.tvnoviny.sk/zahranicne/1752259_ceski-odbornici-stanovili-hodnotu-zivota.-zdravy-clovek-ma-cenu-365-tisic-eur
9. **Mäkká, K., Sventeková, E**. 2014. Risk evaluation by transport of dangerous substances. In: Transport means 2014: proceedings of the 18th international conference. Kaunas: Kaunas University of Technology, Lithuania. ISSN 1822-296X, p 308-311.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Assessment of Connection Quality on Transport Networks Applying the Empirical Models in Traffic Planning: a Case Study

V.Ľupták[1], L. Bartuška[2], J. Hanzl[3]

[1]*Institute of Technology and Business in České Budějovice, Okružní 517/10, 370 01 České Budějovice, Czech Republic,*
E-mail: [1]*luptak@mail.vstecb.cz,* [2]*bartuska@mail.vstecb.cz,* [3]*hanzl@mail.vstecb.cz*

Abstract

In terms of transport infrastructure, the role of the European Transport Policy is to provide comprehensive services of the territory of the European Union the Member States. High-quality transport infrastructure is one of the basic conditions for the proper and efficient functioning of national economies. It can be stated that, from a spatial point of view, the EU transport network is relatively well developed and sufficiently covering the territory of all EU member states. However, in terms of the demands placed on the infrastructure, quality of transport network is very poor. There are also regional differences in the quality of transport networks which has far-reaching consequences for the increase in economic and social disparities between different parts of the EU.
KEY WORDS: *quality, transport network connection, Nyvig model, Lilly model, traffic planning*

1. Introduction

Transport is generally an important aspect of economic development and an integral part of everyday life in every modern company. Nowadays when everything is expressed in monetary terms, new money-saving solutions are being sought. In public passenger transport there are activities intended to creation of integrated transport systems, which result in savings in terms of money and time, which is in synergy [1].

In terms of transport infrastructure, one of the tasks of the Slovak Republic is to ensure the complex serviceability of the territory. Transport infrastructure is one of the basic conditions for the proper functioning of national economy. It can be stated that from a spatial point of view, the transport network in Slovakia is well developed and covers sufficiently the territory of the Slovak Republic. Compared to more developed European countries, especially regarding the demands placed on it, its quality is very poor. There are also considerable regional differences in the quality of transport networks, which has far-reaching consequences reflecting in the increase of economic and social differences between the individual regions.

The quality of the offered connections also refers to the services provided in the transport sector. The main task of transport is to satisfy the customers´ demands for quality, flexible, rapid and safe transportation of passengers and goods. The quality is perceived differently from the transport services user´s and provider´s or operator´s point of view as well as global societal point of view. This is due to the fact that the quality is accessed in a non-systematic manner, regardless the interaction of the passengers and the transport or transportation system.

In the contribution, empirical models are applied in transport planning for a pre-selected route. Due to the complexity of identifying customers´ transportation demands in two largest Slovak towns, Bratislava and Košice, the Lill´s (gravitation) model will be applied in this connection, and new connections will be proposed.

2. Empiric Models in Transport Planning

In transport planning, there are situations when a reasonable estimate is necessary to determine the traffic flow size between two points in a given period of time. Those are situations when it is not possible to conduct a direct transport demand survey.

In some cases, it is also necessary to determine the impact of the individual measures taken by the given transport sector on the transport share size. This applies especially to the number of changes in transport fee, number of connections or transport distance.

For these reasons, empiric models are applied for determining the characteristics of the passenger flow (Lill´s and Nyvig´s models), which is closely related to the number of connections offered within the network [1, 2].

Lill´s model

Lill´s model serves for determining the approximate number of journeys between two settlement units. The distance between them is usually considered in terms of distance between the centres. The Lill´s model is usually expressed as follows:

$$j_{1,2} = \frac{A_1 * A_2}{d^n} * K \ , \tag{1}$$

where $j_{1,2}$ – the number of journeys between two points per given period of time; $A_{1,2}$ – number of inhabitants of the concrete points (in thousands); d – distance between the towns; K – coefficient (it depends on the character and the connection of the points 1 and 2); N – variable with a value close to 2 [3].

Nyvig´s model

Nyvig´s model serves to identify the transport shares of individual transport sectors in a given section. According to this model, it is possible to estimate the impact of input values changes on the changes in transport sectors.

Nyvig´s model is expressed as follows:

$$w_i = \frac{1}{C_i} * \frac{1}{D_i} * S_i * K \ , \tag{2}$$

where for each (i-th) transport sector: w_i – weight of the given transport sector; C_i – price for carriage; Di – time required for transport; S_i – number of connections; K – coefficient (equal for all transport sectors).

While for each transport sector it hold true that [3]:

$$\sum_i w_i = 100\% \ . \tag{3}$$

Application of Lill´s model on Bratislava – Košice route

When applying the model in the section between Bratislava and Košice, it is necessary to take into consideration the number of inhabitants of the individual towns, the number of journeys between the towns, the coefficients and distance between them, since without these factors the creation of the model, as well as the subsequent comparing with the existing number of connections between the settlement units would not be possible [4-7].

The number of connections between Bratislava and Košice is determined by the number of routes between the towns. However, they are routed through various tariff points within the transport network, which a very important aspect; a consensus must be found between the transport sectors and the resulting distance for the Lill´s gravitation model must be determined [5].

Determining resulting distance for gravitation model

The number of public transport connections offered on the route between Bratislava and Košice involves the following transport sectors (Figs. 1-3, Tables 1-2):

- Rail transport;
- Road transport;
- Air transport [18].

For each transport sector, it is necessary to identify the distance between the transport points and determine the resulting distance [8].

Rail transport services:

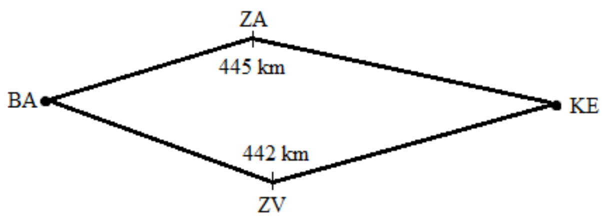


Fig. 1 Distance between settlement units in km – rail transport

Table 1

Average distance – rail transport

Route	Distance [km]		∅ Distance [km]
	BA – ZV – KE	BA – ZA – KE	
Bratislava – Košice	442	445	$\varnothing l = \frac{442+445}{2} = 443.50$ km

Source: authors

Road transport services:

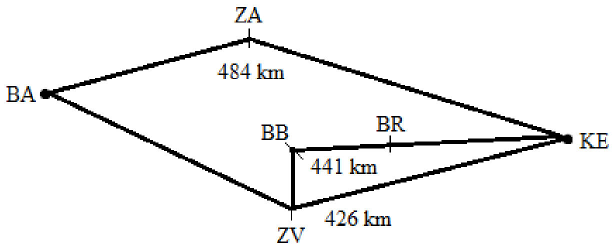


Fig. 2 Distance between settlement units in km – road transport

Table 2

Average distance – road transport

Route	Distance [km]			∅ Distance [km]
	BA – ZV – RS – KE	BA – ZA – KE	BA – ZV – BB – KE	
Bratislava –Košice	426	484	441	$\varnothing l = \frac{426+484+441}{3} = 444$ km

Source: authors

Air transport:

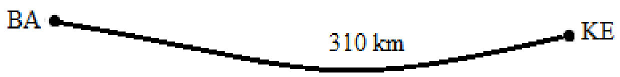


Fig. 3 Distance between settlements in km – air transport

The following Table 3 shows the necessary indicators of relation for Lill´s gravitation model. The number of inhabitants is determined on the basis of the population census of 31 December, 2014 [16].

Table 3

Summary of average distances

Town	Number of inhabitants [thousands]	Distance between towns [km]		
		∅ Rail Transport	∅ Road transport	∅ Air transport
Bratislava	419,68	443	444	310
Košice	239,46			

Source: authors

Number of connections between Bratislava – Košice

The number of connections offered by a transport company depends on the transport services demand from the existing customers (passengers) who for objective or subjective reasons need to move from one location to another between two points situated within the transport network. The connections offered sometimes do not reflect the real demand for transport; it is therefore necessary to apply empiric models in transport planning and thus find out about possible excess or lack of connections between two settlement units, which is in our case between Bratislava and Košice [9].

Table 4 shows the existing average number of connections per day between settlements units, namely Bratislava and Košice, in both directions [17].

Table 4

Number of connections between settlement units

Towns	Number of connections between settlement units					
	Košice → Bratislava			Bratislava → Košice		
	Rail Transport	Road Transport	Air Transport	Rail Transport	Road Transport	Air Transport
Bratislava –Košice	20	7	2	24	12	2

Source: authors

Fig. 4 shows percentage of individual transport sectors involved in the number of connections between Bratislava – Košice. The largest share is in rail transport, which with its 44 connections accounts for a 66% share. The road transport with its 19 connections accounts for 28 %, while 4 connections offered by air transport account for 6 % [10-12].

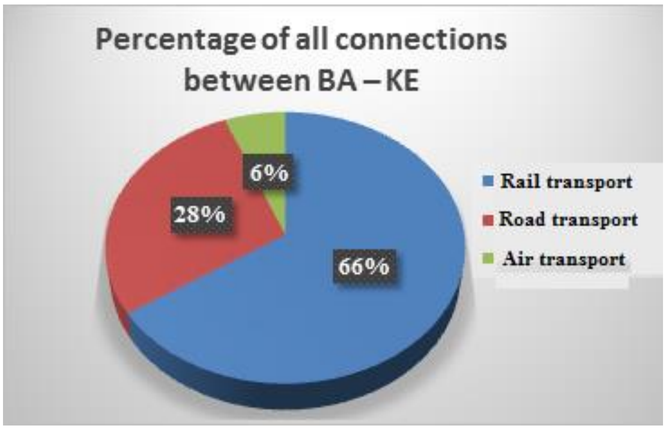


Fig. 4 Percentage of connections between Bratislava and Košice in both directions

Application of Model

The analysis of the existing connections between Bratislava and Košice showed the overall number of connections between these towns. After aggregating all transport sectors connections, 67 connections per 24 hours are introduced. The day analysed was Friday, in particular 25 September 2017. After finding the number of connections, approximate number of connections between Bratislava and Košice can be determined using Lill´s gravitation model and the lack or excess of connections between the settlement units is compared. Table 5 shows the input values of the model [13].

Table 5

Input values of the model

Indicator	Indicator meaning	Indicator value	
$j_{1,2}$	Number of journeys between the two towns per a given period of time	x	
$A_{1,2}$	Number of inhabitants (in thousands) of concrete towns	Bratislava	Košice
		419,68 thousand	239,46 thousand
d	Distance between towns	443 km	
K	coefficient (depends on the character and connection between the towns 1 and 2)	150	
n	variable with a value close to 2.	2	

Source: authors

Input data for determining the number of connections per 24 hours between Bratislava and Košice, distance between them 443 km, with the application of the Lill´s model. The value of coefficient *n* is 2, coefficient *K* is 150 [14].

$$j_{1,2} = \frac{A_1 * A_2}{d^n} * K = \frac{419{,}68 * 239{,}68}{443^2} * 150 = 76{,}88 \doteq 77 \text{ connection/day} .$$

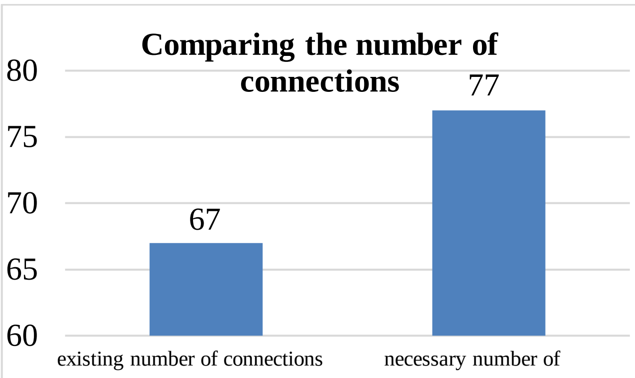


Fig. 5 Comparing existing and necessary number of connections

After completing the values into the model while regarding all indicators and coefficient, the necessary number of connections between Bratislava and Košice is 77 per 24 hours. Compared to the existing connections (Fig. 5), the model considers an increase by 10 connections per 24 hours, which means the serviceability of the settlement units does not correspond with the model [15].

3. Conclusion

The objective of the contribution is to propose a methodology for determining the necessary number of transport connections between settlement units in passenger transport. From the passenger´s point of view it is necessary to take into consideration the availability of transport possibilities between the selected towns within the transport network. Transportation between A and B is affected the transportation time, number of transfers and travel opportunities, no matter if it is road, rail or air transport. The number of links and connections is thus influenced by more factors. This is the starting point for applying empiric models in transport planning.

References

1. **Černá, A.; Černý, J.** 2014. Manažérske rozhodovanie v dopravných systémoch, Univerzita Pardubice, pp. 230, ISBN 978-80-7395-849-7.
2. **Dedík, M.** 2016. Hodnotenie kvality spojenia v osobnej železničnej doprave zo sieťového hľadiska. Diplomová práca. Žilinská univerzita v Žiline, Žilina, pp. 105.
3. **Drdla, P.** 2014. Osobní doprava regionálního a nadregionálního významu. Univerzita Pardubice, 1. vydanie Univerzita Pardubice, pp. 412, ISBN 978-80-7395-787-2.
4. **Gašparík, J., et al.** 2016. Mechanika v železničnej doprave, 1. vydanie - Žilina: Žilinská univerzita v Žiline, 278 s., ISBN 978-80-554-1274-0.
5. **Hrabáček, J.** 2010. Periodická doprava na dopravních sítích a její optimalizace. Dizertačná práca, Univerzita Pardubice, Pardubice.
6. **Ľupták, V.; Gašparík, J.; Kurenkov, P.V.; Meško, P.** 2017. Methodology for assessing transport connections on the integrated transport network, In: Communications: scientific letters of the University of Žilina 19(2), ISSN 1335-4205.
7. **Ľupták, V.** 2017. Hodnotenie kvality spojenia na dopravnej sieti v osobnej doprave. Dizertačná práca, Žilinská univerzita v Žiline, Žilina.
8. **Pečený, L.** 2014. Štandardy kvality poskytovaných služieb v regionálnej osobnej železničnej doprave. Dizertačná práca, Žilinská univerzita v Žiline, Žilina.
9. **Kampf, R.; Gašparík, J.; Kudláčková, N.** 2012. Application of different forms of transport in relation to the process of transport user value creation, Periodica Polytechnica Transportation Engineering 40(2): 71-75.
10. **Kampf, R.; Stopka, O.; Kubasakova, I.; Zitrický, V.** 2016. Macroeconomic Evaluation of Projects Regarding the Traffic Constructions and Equipment, In: Procedia Engineering 161: 1538-1544.
11. **Cerna, L.; Zitricky, V.; Ponicky, J.** 2016. Income and price elasticity of demand for transport services in rail passenger transport in the Slovak republic In: Mathematical methods in economics, MME 2016, ISBN 978-80-7494-296-9. - p. 126-131.
12. **Zitrický, V.; Gašparík, J.; Pečený, L.** 2015. The methodology of rating quality standards in the regional passenger transport, In: Transport problems 10: 59-72.
13. **Kudláč, Š.; Štefancová, V.; Majerčák, J.** 2017. Using the Saaty Method and the FMEA Method for Evaluation of Constraints in Logistics Chain, Procedia Engineering 187: 749-755.
14. **Vojtek, M.; Kendra M.; Zitrický, V.; Daniš, J.** 2017. Principles of logistics applied to railway passenger transport In: MATEC Web of Conferences, 8th International Scientific Conference, LOGI 2017, 19th October, Ceske Budejovice; Czech Republic, Vol. 134.
15. **Blaho, P.; Šulko, P.; Černá, L.; Dolinayová, A.** 2017. Draft proposal of determining charges for stabling of rolling stock within the ŽSR railway network, In: MATEC Web of Conferences, 8th International Scientific Conference, LOGI 2017, 19th October, Ceske Budejovice; Czech Republic, Vol. 134.
16. **Poliaková, B.; Kubasáková, I.** 2014. The problematic implementation of integrated transport systems in Slovakia, Autobusy: technika, eksploatacja, systemy transportowe 5, 104-110. ISSN 1509-5878.
17. **Stopka, O.; Bartuska, L.; Kampf, R.** 2015. Passengers' evaluation of the integrated transport systems, Nase More 62(3): 153-157. DOI: 10.17818/NM/2015/SI12.
18. **Stopka, O.; Ponický, J.; Chovancová, M.; Zitrický, V.** 2016. Draft method for determining the number of checking devices utilized within the regional passenger transport, Nase More 63(3): 200-203. DOI: 10.17818/NM/2016/SI23

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Scale with a Built-in Three-Axis Acceleration Sensor for Applications in Sea Transport

I. Bester[1], M. Chrzan[2]

[1]*Kazimierz Pulaski University of Technology and Humanities in Radom, Malczewskiego 29, 26-600 Radom, Poland, E-mail: ireneusz.bester@gmail.com*
Kazimierz Pulaski University of Technology and Humanities in Radom, Malczewskiego 29, 26-600 Radom, Poland, [2]*E-mail: m.chrzan@uthrad.pl*

Abstract

The article discusses the use of the scale C32HR.60 series from "Radwag Wagi Elektroniczne" company in sea transport. The article presents the structure, operating principles, technical capabilities of the device and discusses the innovative use of a three-axis acceleration sensor in the scale. The next part of the article gives examples of applications as well as the advantages of using the C32HR.60 scale in sea transport.

1. Introduction

The working environment of the scale on the vessel is very demanding. As a result of the vessel's movement during sailing in rough water, the following phenomena occur: pitching (the up/down rotation of a vessel), rolling (transverse and longitudinal oscillations), yawing, heaving, swaying (longitudinal rolling) and surging [1, 5, 6]. However, the metrological requirements for scales working in sea conditions are identical to those for stationary scales [8]. Therefore, the marine scale must have appropriate algorithms of swinging and pitching compensation in order to obtain a mass measurement result burdened with the smallest possible error.

2. Intended Use

C32HR.60 marine scale is a device intended for use on ships and boats both in high humidity conditions and in direct contact with water. The scale has been equipped with special system for control and compensation of platform tilt, which when combined with electronic components of high class guarantees absolute precision, very fast measurement and excellent repeatability.

2.1. Scale Construction

The C32HR.60 platform scale, made of AISI 316 stainless steel, is a device of IP68/69 protection class. Use of the battery enables the scale to be operated even when there is either no or unstable power supply. The battery comes standard with the scale. The C32HR features 5" color graphic display, ensuring perfect readability, and 22-key membrane keypad with freely programmable function keys. Due to a customized menu, all operator's individual needs can be met, which makes the operation even more intuitive and simple [3].

2.2. Technical Specifications of the Scale

Technical specifications of the marine scale C32HR.60 were presented in Table 1.

Table 1

Max capacity	60 kg
Readability	50 g
Tare range	-60 kg
Pan size	400 × 600 mm
Working temperature	0° ÷ +40°C
Storage temperature	-25° ÷ +70°C
IP rating	IP 68/69 construction and load cell, IP 68 indicator
Power supply	100 ÷ 240 V AC 50/60 Hz and battery
Optional power supply	24V DC
Display	5" graphic colour

2.3. Communication Interfaces

Numerous communication interfaces enable network communication and cooperation with peripheral devices such as computer, barcode scanner or printer:

- RS 232 (computer, printer, barcode scanner, transponder card reader).
- USB type A (printer, USB flash drive).
- Ethernet (wired LAN communication, barcode scanners).

The arrangement of communication interface connectors on the back cover of the scale case with an example configuration of peripheral devices is shown in Fig. 1.

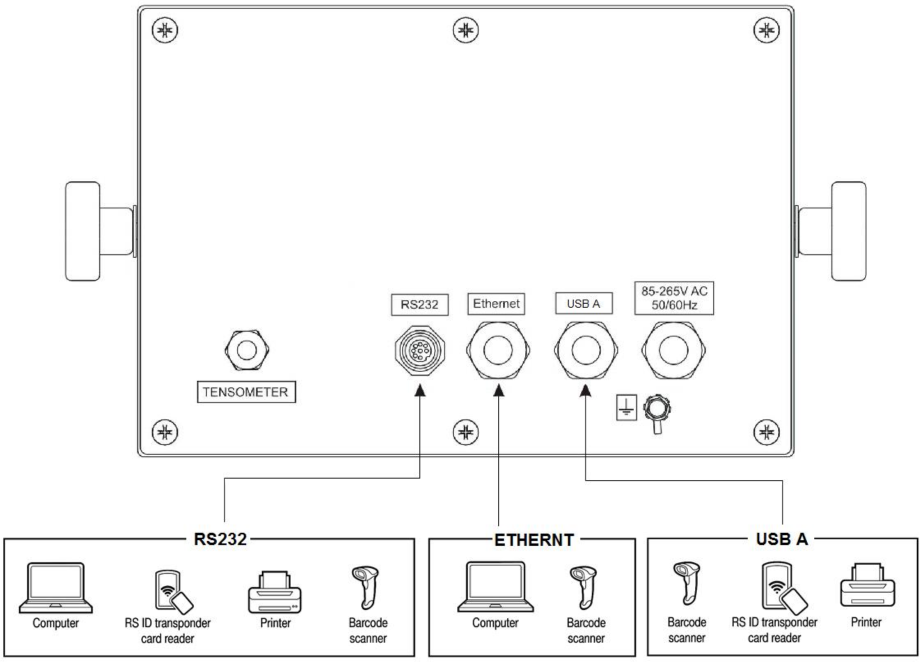


Fig. 1 Communication interface of the marine scale C32HR.60 [own study]

2.4. Characteristics of the LIS3DSH Three-Axis Acceleration Sensor

The LIS3DSH is an ultra-low-power high performance three-axis linear accelerometer belonging to the “nano” family with embedded state machine that can be programmed to implement autonomous applications.

The LIS3DSH it is capable of measuring accelerations with output data rates from 3.125 Hz to 1.6 kHz. The self-test capability allows the user to check the functioning of the sensor in the final application. The device can be configured to generate interrupt signals activated by user defined motion patterns [4, 7].

The LIS3DSH has an integrated first in, first out (FIFO) buffer allowing the user to store data for host processor intervention reduction. The LIS3DSH is available in a small thin plastic land grid array package (LGA) and it is guaranteed to operate over an extended temperature range from -40°C to +85°C [4].

Features:

- Wide supply voltage, 1.71V to 3.6V;
- Independent IOs supply (1.8 V) and supply voltage compatible;
- Ultra low-power consumption;
- I2C/SPI digital output interface;
- 16-bit data output;
- Programmable embedded state machines;
- Embedded temperature sensor;
- Embedded self-test;
- Embedded FIFO.

Applications:

- Motion controlled user interface;
- Gaming and virtual reality;
- Pedometer;
- Intelligent power saving for handheld devices;
- Display orientation;
- Click/double click recognition;
- Impact recognition and logging;
- Vibration monitoring and compensation.

The block diagram of the LIS3DSH accelerometer is shown in Fig. 2.

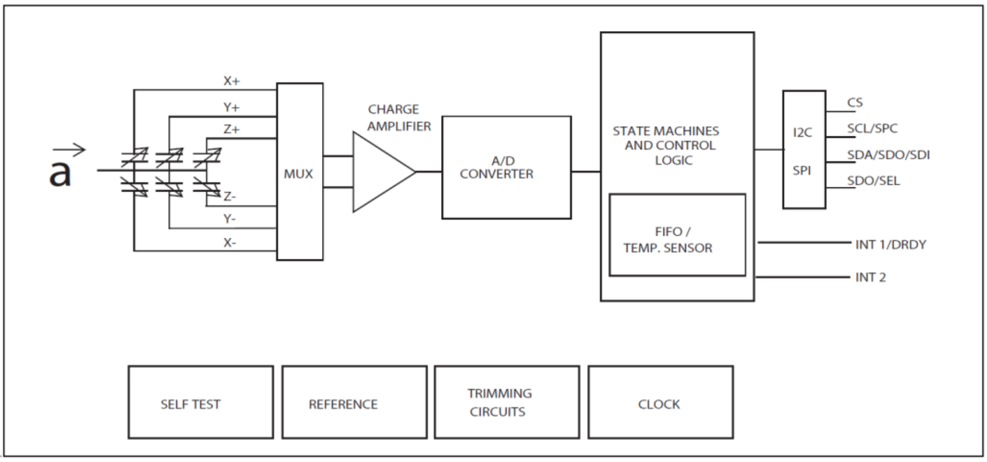


Fig. 2 LIS3DSH block diagram [4]

The LIS3DSH embeds two state machines able to run a user defined program. The program is made up of a set of instructions that define the transition to successive states. The graph of the transition of such an automaton is shown in Fig. 3.

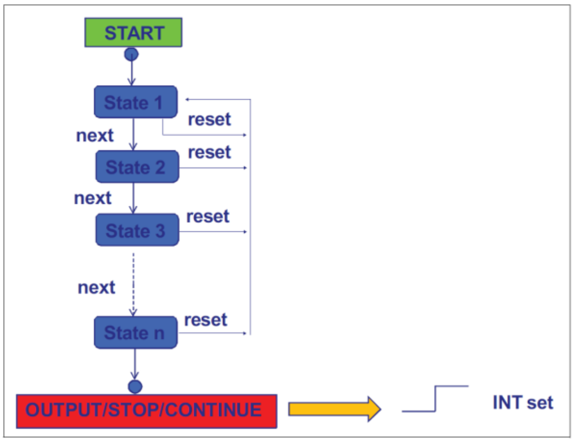


Fig. 3 LIS3DSH state machines: sequence of state to execute an algorithm [4]

2.5. Scale Software

Complex software allows carrying out many tasks connected with mass measurement, e.g. parts counting, labelling, checkweighing and statistics. Marine scale has a friendly, graphical user interface with the possibility of its configuration using widgets, which in combination with a large, high-resolution color display ensures easy and unambiguous transmission of information about the current state of the process. Color bar graph signals whether the weighing result is within declared thresholds thus significantly influencing performance.

The scale works with barcode scanners and label printers, which will be appreciated by users who use scales in the process of counting pieces, labeling and other tasks where unambiguous identification of weighted fish is necessary.

Table 2

Databases / Reports	Maximum number of records
Products	15 000
Operators	500
Packaging	500
Customers	500
Universal variables	100
Non-standard printouts	10
Weighings	50 000
ALIBI	500 000

Various permissions levels assure safety of stored data and prevent unauthorized operators from modifying the settings. Complex databases of products, packaging and customers are very important for operators working with wide range of products and having an extensive sales network [3]. The list of databases and reports together with maximum numbers of records are presented in Table 2.

2.6. Computing Software

Marine scale cooperates with the following computer software of the company „Radwag Wagi Elektroniczne":

– RLAB performing functions of collection, presentation and statistical analysis of measurements sent from scales (Fig. 4). The program provides advanced functions of generating and personalizing charts and reports.

– RADWAG CONNECT allowing to connect with the scale via a local network, giving access to their basic functions: taring, zeroing, weighing records, exporting measurements (Fig. 5). It uses any desktop or mobile device with Windows 10: a desktop computer, laptop, tablet or phone.

– ALIBI READER allowing to read data from the scale's ALIBI memory. The ALIBI memory stores all measurements made by the scale. The ALIBI memory cannot be modified or deleted in any way, so it can be said that it is a kind of black box of the scale [3].

Fig. 4 The main window of the RLAB program [3]

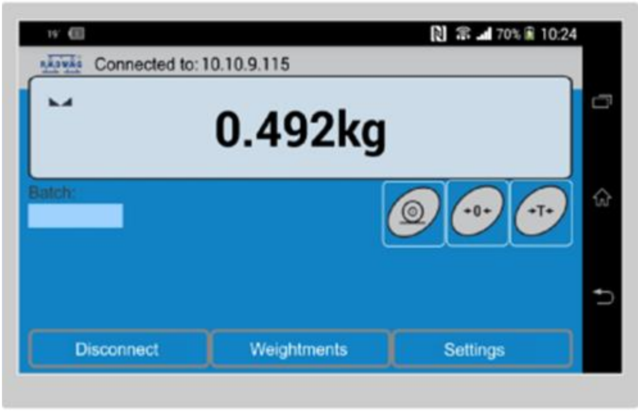


Fig. 5 The main window of the RADWAG CONNECT program [3]

3. The Application of the Scale in the Labelling System

Labelling function enables marking products with weight labels. This makes product identification fast and easy. The labels can provide data such as: date, batch number, lot number, fishing area, cutter name, fish weight, pictogram, Ean-13 code with weight value and product code [2]. Labeling enables:

- Creating a database of labels in the scale.
- Assigning an individual label for a given product or common for all goods.
- Printing of collective labels (box) with weight and quantity sum.
- Automatic triggering of bulk label printing.

Designing labels and sending them to the scale's memory is possible using dedicated computer software "Label Editor R02" of the company "Radwag Waga Elektroniczne". The main window of the "Label Editor R02" is shown in Fig. 6.

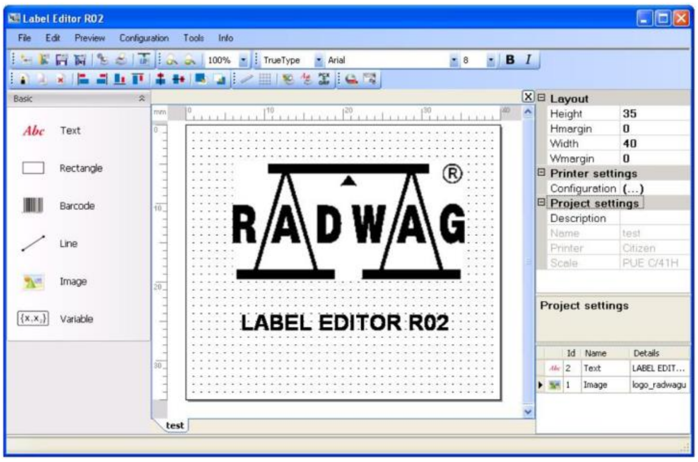


Fig. 6 The main window of the "Label editor R02" computer program [3]

4. Conclusions

The general structural standard of marine scales is the use of an additional tensometric beam acting as a swaying and pitching sensor. The use of the three-axis LIS3DSH acceleration sensor in the C32HR.60 marine scales is an innovative solution of the company "Radwag Wagi Elektroniczne", which allows to reduce significantly errors of indications. In the range of small deviations, the use of a three-axis acceleration sensor also allows you to obtain a more sensitive measurement of level changes several times. An additional algorithm for temperature stabilization of the acceleration sensor and the implementation of advanced mathematical analysis in the C32HR.60 marine scale software allows to eliminate efficiently the influence of substrate instability on the mass indication.

References

1. **Wełnicki, W.** 1989. Mechanika ruchu okrętu. Gdańsk: Politechnika Gdańska (in Polish).
2. **Misiewicz, T.** 2015. Automatyzacja pomiarów masy. Radom. Biuletyn Radwag Wagi Elektroniczne, pod redakcją Tomasza Misiewicza (in Polish).
3. Radwag Wagi Elektroniczne [online cit.: 23.05.2018r] Available from: http://www.radwag.com
4. LIS3DSH accelerometer [online cit.: 23.05.2018r]. Available from: http://www.st.com/content/ccc/resource/technical/document/datasheet/23/c3/ea/bf/8f/d9/41/df/DM00040962.pdf/files/DM00040962.pdf/jcr:content/translations/en.DM00040962.pdf
5. **Kazama, A; Aono, T; Okada, R.** High Shock-Resistant Design for Wafer-Level-Packaged Three-Axis Accelerometer With Ring-Shaped Beam, Journal Of Microelectromechanical Systems 27(2): 355-364. DOI: 10.1109/JMEMS.2018.2808165 Published: APR 2018
6. **Sun, HJ; Geng, F; Yu, T; Liu, ZQ.** 2017. Anti-vibration analysis of vortex probe based on three-axis acceleration measurement. Flow Measurement and Instrumentation 58: 21-30. DOI:10.1016/j.flowmeasinst.2017.09.003 Published: DEC 2017.
7. **Ogami, Y; Murakita, N; Fukudome, K**. 2017. Computational Experiments on the Step and Frequency Responses of a Three-Axis Thermal Accelerometer, Sensors 17(11) Article Number: 2618 DOI: 10.3390/s17112618 Published: NOV 2017.
8. **Huang, Jian** 2017. Principle and Application of Angle Sensor Based on Acceleration. Proceedings of the 2017 7th International Conference on Education, Management, Computer and Society (Emcs 2017) Edited by: Jing, W; Guiran, C; Huiyu, Z Book Series: ACSR-Advances in Comptuer Science Research 61: 1481-1486. Published: 2017 Document Type: Proceedings Paper.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Evaluation of the Service Quality Performed by the Rail Passenger Transport Carriers on the Prague – Ostrava Region Route: Primary Marketing Research

J. Chocholáč[1], M. Trpišovský[2], N. Kudláčková[3]

[1]*University of Pardubice, Faculty of Transport Engineering, Studentská 95, 53210, Pardubice 2, Czech Republic, E-mail: jan.chocholac@upce.cz*

[2]*University of Pardubice, Faculty of Transport Engineering, Studentská 95, 53210, Pardubice 2, Czech Republic, E-mail: martin.trpisovsky@student.upce.cz*

[3]*University of Pardubice, Faculty of Transport Engineering, Studentská 95, 53210, Pardubice 2, Czech Republic, E-mail: nina.kudlackova@upce.cz*

Abstract

The article is focused on the presentation of the outcomes from the primary marketing research concerning the service quality performed by the rail passenger transport carriers on the Prague – Ostrava region route, which is main long distance rail line with in market competition in the Czech Republic. Historically it was operated by the Czech national carrier, former incumbent České dráhy (Czech Railways Company). Since 2011 it is opened to the competition of two competitors as RegioJet entered the market, soon afterwards in 2012 third competitor joined the passenger railway market on this route – LEO Express. The research aims to analyze the quality as perceived by the passengers comparing the service experience during the journey with all three aforementioned carriers. The primary marketing research was carried out in the form of structured personal questioning, where the analyzed criterions were ticket prices, carriage convenience, customer service and the train staff behavior during the journey, tidiness of carriage interiors, frequency of offered connections and the refreshment offer during the journey. The evaluation and discussion of the outcomes are included in the article.

KEY WORDS: *quality of service, public transport, railway passenger transport, marketing research*

1. Introduction

Ever since it was introduced the railway transport became an essential part of many country economics thanks to its dynamical development. This phenomenon didn't pass the Czech Republic, respectively all states in the area of the present time Czech Republic. The railway transport is indeed not only the circulation system of the economics, but the railway system itself is a specific industrial branch. Like in the other industrial branches the railway transport performance is also confronted with growing competition, customer behavior and requirement changes and with challenges of company delimitation in the market environment [1, 2].

The aim of European railway transport policy is to create unified railway area and thus to open this industrial branch to the competition. Above stated is supported by four railway legislation packages that subsequently open the market of railway transport to competition. The Czech opened market of railway transport operated on commercial basis was entered by several carriers in recent years.

Until 2011 the passenger railway transport on the route from Prague to Ostrava region was provided only by the Czech Railways company (České dráhy, a.s.). With respect to the fact, that the RegioJet company announced the interest in entering the passenger railway market on this route the Ministry of Transport of the Czech Republic gradually excluded the connections on this route from the state order of public transport services provided in general economic interest in order to provide non-discriminatory competitive environment on the market of this route. The competition was started in September 2011 when RegioJet started to operate their trains on the Prague – Ostrava region route. One year later another company of LEO Express entered this route too. Since 2012 the passengers on this route of Prague – Ostrava region can choose from services provided by three different companies – newcomers RegioJet and LEO Express and the incumbent of Czech Railways Company who lost its dominant position here and was forced to react.

The quality of public transport services in passenger transport is a set of intangible variables. The quality of public transport services in passenger transport can be assessed by four different approaches [3, 4]:

1. The user's point of view – the quality perceived by passenger, according to the research the passengers mostly appreciate total time, comfort and cleanliness, accessibility of the service, accessibility of the information, service organization, safety, the behavior of transport company employees and conductors and their costs, i.e. the fare [5-9].
2. The operational efficiency – the assessment of technical-economic indicators describing the transport processes including the assessment of indicators describing the labor's work [3].
3. The operation economics – business point of view performed by the carrier responsible for operation [10].

4. The efficiency of usage of allocated resources by the public competent authorities in charge of public transportation services – in the Czech Republic it is the point of view of the territorial administrative organs (municipalities, regions, Ministry of Transport) [4, 11].

This article aims to the evaluation of the service quality of provided railway transport services by the carriers on the route Prague – Ostrava region from the service users' point of view, i.e. the passengers' point of view. The research form is primary marketing research among passengers on this route.

2. Problematics Statement

Scientist as well as public transport carrier's management focuses more on the quality management of provided services recently [12]. They monitor the quality regularly, evaluate it and provide relevant managers decisions that are supposed to reflect the outcomes of the service quality evaluation carried by the customers as documented [13, 14].

Sánchez Pérez et al. and Tsami and Nathanail proved the direct dependence between the quality of provided services and the customers shopping behavior in public transport services sector [15, 16]. This premise was confirmed by Tsami and Nathanail who added a fact that passengers formulate their optimal strategy for a particular journey before its very realization and in case of possible choice between more transport modes or more carriers providing the same transportation from A to B they asses which service they use considering the service quality of different carriers as the most important factor [17]. A study of Henser and Houghton referred to the quality level of service demanded by the competent authorities specified in the public transport contract concluded with carriers, very often they demand regular assessment of the quality level of public transport services provided in general interest [18]. The growing emphasis on quality monitoring and assessment in the form of customer satisfaction surveys is confirmed by Hensher and Stanley in their scientific article [13]. Dell'Olio, Ibeas and Cecín identified another carriers' interest that is the continual growth of quality of their transportation services besides the quality monitoring and the effort of maximal saturation of customer needs [19]. Becker and Albers claim that the carriers in passenger public transport focus more on quality improving as it directly leads to their economical outcome [12]. Hensher and Stanley introduced another important reason leading to more intense carriers' effort to provide the higher quality services, they analyzed the contractual conditions in public transport services contracts and found out that the carriers are in risk of financial sanction in case of not meeting the demanded service quality [20]. It can also lead to the exclusion from the next bidding competition and thus to losing the possibility to get another public transport services contract.

Tsami and Nathanail emphasize that the issue of public transport services quality was studied from the marketing and management point of view as well as from the social science point of view [17]. Among the other one the GAP model is well-known and mostly used public transportation services quality assessment models designed by Parasuraman, Zaithaml and Berry, the GAP model uses the combination of customer and provider point of views, i.e. the passengers and carriers marketing specialists point of view [21]. It identifies gaps in five defined areas: the gap between the customers' expectations and the perception of customers' expectations by the company's management, the gap between the customers' expectations and the perception of customers' expectations by the company's management and the quality specification of offered service, the gap between the quality specification of offered service and the actual service quality provided, the gap between the offered service quality and the communication of this quality towards customers, the gap between the service quality expected by the customer and the provided service quality perceived by customer [21].

European Committee for Standardization (CEN) issued the norm of EN 13816, this norm was transposed into the Czech norm ČSN EN 13816. This norm specifies the requirements on defining, aims and measurement of passenger public transportation services. The main aim of this norm is, according to the EN 13816, to support the qualitative approach in public transportation services and to focus on the needs and expectations of the customers by using defined procedure specification. EN 13816 defines a set of recommended criterions to measure the public transport services quality; these are divided into eight categories: Availability – the extent of provided services in means of geography, time and frequency; Accessibility – the access to the public transportation system including the connection between different transport modes; Information – systematic presenting of information and observations about the passenger public transportation system that help to plan and realize the journeys; Time – all time aspects important for planning and realizing journeys; Customer care – the service elements introduced in order to harmonize individual customer requirements and provided service standard; Comfort – the service elements introduced in order to make the public transport services usage comfortable and pleasant to passengers; Safety – the feel of personal safety truly perceived by passengers that come up from the actual established measures and activities dedicated to the customers realization of these measures; Ecological impact – the minimization of negative influence to the environment. [22]

Eboli and Mazzulla defined criterions that characterize the quality of services provided in public transportation, they included: the availability of services, the reliability of services, comfort, cleanliness, safety, availability of information, customer care and ecological impact [23]. Vuchic added the criterions of accessibility of services and transport time [24]. Dell´Olio, Ibeas and Cecín analyzed also the criterions of vehicle occupancy and waiting time at public transport stops as a part of their research [19]. Paulley et al. focused on the issue of public transport services demand, they confirmed that there is a direct relation between transport fares and the quality of provided services [25].

Tsami and Nathanail investigated different public transportation services quality indicators, they focused on routing, amount of stops, their location and distance, the frequency of transport connections, daily operation times, reliability and punctuality, comfort, air-conditioning of transport means, the noise and vibrations level, the availability

of benches at stops, the cleanliness of the interior and outer surface of transport vehicles, the availability of information about the route in vehicles, at stops etc., the availability of information accessible from the mobile phone, online etc., the safety, professionality and look of the stuff, the process of complains handling, the usage of ecofriendly vehicles and the simplicity of ticket purchasing [17].

The quality of public transportation services was historically in the Czech Republic and in former Czechoslovakia fully missed out. The quality accent appeared in last decade when the competent authorities (Ministry of Transport, regions and municipalities) realized their role and significance in the system and they require quality standards. These standards shall be met by the railway carriers as they concluded the public transportation services contracts that include this obligation [26]. The default of meeting the requirements lead to the financial sanction.

Competent authorities require certain quality level which they state in the public transportation services contract. This article focuses on the Czech specific case of open access competition on the route of Prague – Ostrava region where no contracts defining quality are concluded. The insufficient public transportation quality at this route can lead to more negative impact on the carrier than only to financial sanction. Jade, Molková and Kvizda introduced the concept of customer empowerment when the change from Czech Railways' monopolistic position on the transport market only feebly considering customer needs and wishes to the highly competitive market with three carriers led to the revolutionary change of roles, passengers become empowered to dictate the quality requirements and the carriers must meet them if they wish to survive [1]. The meeting of customer needs and wishes is crucial to build a relation between the carrier and customers. The quality growth connected to the beginning of the competitive environment leads to total change on this market.

3. Methods

The method of primary marketing research was chosen for the evaluation of the service quality performed by the rail passenger transport carriers on the Prague – Ostrava region route. The primary marketing research was realized as structured personal questioning, while respondents were chosen in quotas in order to reach the representative sample.

Kozel et al. define the marketing research formula to set the right extend of selective sample. In this formula *n* is the minimum amount of respondents, *z* is the coefficient of reliability (when set as 1 the statement probability is at least 68.3%, when set as 2 the probability of 95.4% is ensured and when z set as 3 then the probability reaches at least 99.7%); *p* and *q* are the amounts of respondents that are familiar with the issue (expressed in percent). When the values of *p* and *q* aren't known exactly the maximum product is used, i.e. $p = 0{,}5$ and $q = 0{,}5$; Δ is the set maximum acceptable incorrectness (5% corresponds to $\Delta = 0{,}05$). [27]

$$n \geq \frac{z^2 \times p \times q}{\Delta^2}; \tag{1}$$

$$n \geq \frac{2^2 \times 0{,}5 \times 0{,}5}{0{,}05^2} \geq 400. \tag{2}$$

After substitution in the Eq. (1) the minimum amount of respondents $n \geq 400$ (Eq. (2)) is counted, with that amount the structured questioning sessions were realized. The calculation reflects the probability of statements of 95,4% ($z = 2$) and the maximum acceptable incorrectness of 5% ($\Delta = 0{,}05$).

The marketing research was realized from 1st April 2017 until 30th April 2017, while all the included respondents shall meet the condition that they used all three carriers services on at least a part of the Prague – Ostrava route since 2012 until now.

The respondents evaluated carriers according to six following criteria (*A*-*F*). The criteria were defined on the base of literature background research as following: *A* criterion – fare; *B* criterion – carriage (train) comfort; *C* criterion – customer service and staff behavior during the journey; *D* criterion – cleanliness of the carriages interior; *E* criterion – frequency of offered connections; *F* criterion – refreshment offer during the journey. [17, 19, 22-25]

Each criterion was evaluated on the quantitative scale from 1 to 9, when 1 responds to the worst evaluation, 5 responds to the average one and 9 responds to the best evaluation. With the use of Eq. (3)-(5), where $n = 400$ and *A*, *B* and *C* refers to the carriers Czech Railways (*A*), RegioJet (*B*) and LEO Express (*C*), the provided service quality for each carriers and particular criteria is counted.

$$\bar{x}_A = \frac{1}{n}\left(x_{1A} + x_{2A} + x_{3A} + \cdots + x_{nA}\right); \tag{3}$$

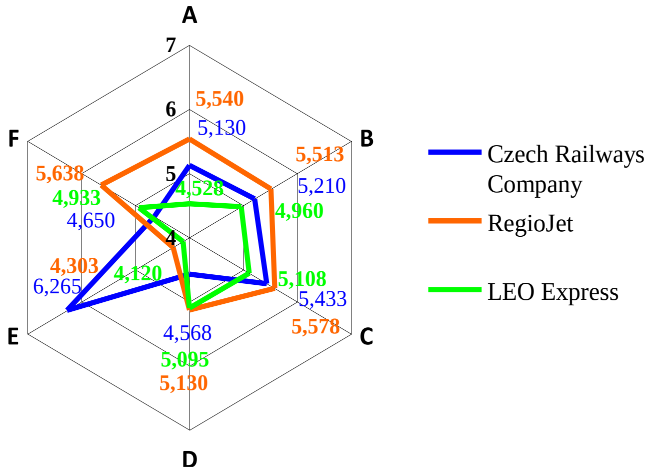
$$\bar{x}_B = \frac{1}{n}\left(x_{1B} + x_{2B} + x_{3B} + \cdots + x_{nB}\right); \tag{4}$$

$$\bar{x}_C = \frac{1}{n}\left(x_{1C} + x_{2C} + x_{3C} + \cdots + x_{nC}\right). \tag{5}$$

The following step included the second grade sorting according to sex and age of the respondents.

4. The Analysis

The Fig. 1 depicts the spider-chart with the outcomes from the provided services quality on the Prague – Ostrava region route evaluation according to the certain criteria for the analyzed carriers.



Criterion	Criterion description
A	Fare
B	Carriage (train) comfort
C	Customer service and staff behavior during the journey
D	Cleanliness of the carriages (train) interior
E	Frequency of offered connections
F	Refreshment offer during the journey

Fig. 1 The provided services quality evaluation outcomes according to particular criteria reached by the carrier of Czech Railways Company, RegioJet and LEO Express [authors]

The evaluation of Czech Railways Company clearly shows that the respondents evaluated four criteria (A, B, C and E) above the average with the arithmetic average of achieved evaluation of given criterion higher than the value of 5.000 while the criterion of frequency of offered connections (E criterion) achieved best evaluation of 6.265. The other above-average-evaluated criteria are the fare (5.130), comfort of the carriage, respectively of the train (5.210) and the customer service and staff behavior during the journey (5.433). The D criterion (cleanliness of the carriages, respectively train interior) and F criterion (refreshment offer during the journey) ranked as below-average-evaluated criteria (the criteria that achieved the arithmetic average of evaluated value of less than 5,000). The worst evaluation by the Czech Railways was reached by the D criterion (cleanliness of the carriages, respectively train interior), where the final evaluation reached the value 4,568.

Five out of six evaluated criteria ranked as above-average-evaluated criteria by the RegioJet carrier, these were the criteria A, B, C, D and F. Only the E criterion (frequency of offered connections) ranked as the below-average-evaluated criterion with the value of 4.303. At the same time it was the criterion with worst evaluation reached by RegioJet carrier. The best evaluated criterion by this carrier was the F criterion (refreshment offer during the journey) with total evaluation value of 5.638.

The provided services quality on the Prague – Ostrava region route evaluation outcomes according to particular criteria reached by the carrier of LEO Express are as follows. The respondents evaluated only two of the criteria as slightly above-average-evaluated criteria; it was the C (customer service and staff behavior during the journey – 5.108) and D (cleanliness of the carriages, respectively train interior – 5.095) criterion. The other four criteria (A, B, E, F) were evaluated as the below-average-evaluated ones. The worst evaluation was reached by the E criterion (frequency of offered connections) with the final evaluation value of 4.120.

Table 1 shows the particular outcomes of the service quality evaluation provided by the carriers according to particular criteria and the total outcomes of the provided service quality. The red color distinguishes the worst evaluation in terms of that particular criterion, in contrary green color highlights the best one. Table 1 shows clearly that the RegioJet company reached the best evaluation in terms of all criteria except the E criterion (frequency of offered connections). The Czech Railways company was evaluated best among the others in terms of the criterion of the frequency of offered connection. LEO Express carrier didn't reach any of the best evaluation in terms of particular criterion. Czech Railways reached the worst evaluation value in two criteria in comparison with the other carriers; these were the D criterion (cleanliness of the carriages, respectively train interior) and F criterion (refreshment offer during the journey). The RegioJet carrier didn't reach any of the worst evaluation unlike LEO Express that reached the worst evaluation in four remaining criteria – A, B, C and E.

The total evaluation of the provided services quality is dominated by the RegioJet carrier (5.283), and then second best is the company of Czech Railways (5.209), both cariers reached the total above-average-evaluation. The worst evaluation was reached by the LEO Express carrier, who was the last one as well as the only below-average-evaluated carrier, total evaluation reached 4.790. The best evaluated criterion among the other criteria in terms of all three carriers was the C criterion (customer service and staff behavior during the journey – 5.373). In contrary the worst evaluated criterion among the others in terms of all evaluated carriers was the E criterion (frequency of offered connections – 4.896). This is the subsequence of the fact that Czech Railways company offers highest amount of connections which leads to their best evaluation unlike the other two carriers RegioJet and LEO Express who offer less connections than Czech Railways, that led to their bad evaluation in their criterion and thus to the overall bad evaluation in terms of all three carriers.

Table 1

Final outcomes of the provided service quality evaluation for the carriers

Criterion	A	B	C	D	E	F	Total
Czech Railways	5.130	5.210	5.433	4.568	6.265	4.650	5.209
RegioJet	5.540	5.513	5.578	5.130	4.303	5.638	5.283
LEO Express	4.528	4.960	5.108	5.095	4.120	4.933	4.790
Average	5.066	5.228	5.373	4.931	4.896	5.073	5.094

Based on the second class sorting according to the sex and age of the respondents as summarized in the Table 2 there is a conclusion that the Czech Railways company reached higher evaluation by men (5.300) than by women (5.121). The RegioJet carrier in contrary reached better evaluation by women (5.302) in comparison with only 5.264 by men. LEO Express reached better evaluation by male respondents (4.801) than by female ones (4.780).

Table 2

Final outcomes of the provided service quality evaluation according to the respondent's sex and age

Criterion	Czech Railways	RegioJet	LEO Express
Sex – women	5.121	5.302	4.780
Sex – men	5.300	5.264	4.801
Respondents with the age of less than 24 years	5.090	5.623	4.842
Respondents with the age from 25 to 34 years	5.538	5.384	4.929
Respondents with the age from 35 to 44 years	5.225	4.844	4.433
Respondents with the age from 45 to 54 years	4.818	5.339	4.615
Respondents with the age of 55 and more years	5.420	5.096	5.120

From the age categories point of view is the Czech Railways company best evaluated by the respondents in the age from 25 to 4 years (5.538), in contrary the worst evaluation is reached by the respondents of the age from 45 to 54 years (4.818). The RegioJet carrier reached the best respondents‘ evaluation in the age group less than 24 years old, in contrary to the age group from 35 to 44 years. The LEO Express Company reached the best evaluation by respondents older than 55 years (5.120). In contrary it reached the worst evaluation by respondents with the age from 35 to 44 years, i.e. the same as by RegioJet carrier.

5. Discussion

The primary marketing research itself is only one of the whole set of researches that need to be done to reach higher level of understanding the customer priorities and behavior not only on this rather specific railway route, but also in general understanding of the process of perceiving quality by passengers in the long distance railway transport in the Czech Republic. The secondary steps following the primary research should focus on particular aspect of provided services perceived quality. The other important task for researchers is to maintain continuous run of the primary research and following the development of its outcomes in time as the carriers react to provided quality perception by their customers as well as the competitive market evolution runs.

A comparison with the outcomes of similar research realized on other routes or on the same route in past, i.e. before the highly competitive market was started there, would be beneficial. In the Czech Republic the passenger railway transport market is slowly opening and new carriers enter other routes than only Prague – Ostrava region too. It is possible to follow the real time changes in provided railway services quality perceiving by passengers and also to verify the theories about quality changes on different routes caused by the market opening. At this time the competitive connections of more carriers on the same route are run also at the Prague – Brno – Vienna / Bratislava route. In the suburban transport a competitive market exists on the Prague – Benešov u Prahy route.

6. Conclusion

The research conclusion shows to significant differences between the quality offered by different carriers. The best evaluated carrier is RegioJet that beats the former monopolistic carrier of Czech Railways in all measured criteria except the criterion of offered amount of connections. Objectively the highest amount of offered connections is provided by Czech Railways that is given among others by its former monopolistic position on the railway transport market and by their status of national carrier. That enables the company of Czech Railways to offer a wide fleet and frequent operation of trains on this route with the efficient connection to other railways in the Czech Republic and abroad. The outcomes show that Czech Railways Company is evaluated significantly better by the older passengers, while in the age group below 24 years RegioJet gains much better evaluation. This fact can be explained by the RegioJet's intense marketing campaign aimed mainly on youth and students, the clarification of this theory is a question of subsequent research though.

Acknowledgment

This article is published within the solution of project no. SGS_2018_023 „Traffic Engineering, Technology and Management".

Reference

1. **Jade, R.; Molková, T.; Kvizda, M.** 2015. Role of railways in empowering travelers: A case study from the Czech Republic, Journal of Rail Transport Planning and Management 5(2): 31-49.
2. **Betancourt, R.; Gautschi, D.A.** 1986. The evolution of retailing. A suggested economic interpretation, International Journal of Research in Marketing 3(4): 217-232.
3. **Silaghi, S.** 2010. Quality of Public Transportation Services in Urban Area of Oradea, The Journal of the Faculty of Economics – Economic 1(2): 469-474.
4. **Cruz, L.; Barata, E.; Ferreira, J.-P.** 2012. Performance in urban public transport systems: a critical analysis of the Portuguese case, International Journal of Productivity and Performance Management 61(7): 730-751.
5. **D'Ovidio, F.D.; Leogrande, D.; Mancarella, R.; Schinzano, A.; Viola, D.** 2014. A multivariate analysis of the quality of public transport services, Procedia Economics and Finance 17: 238-247.
6. **Shiftan, Y.; Sharaby, N.** 2012. The Impact of Fare Integration on Travel Behavior and Transit Ridership, Transport Policy 21: 63-70.
7. **Dell'Olio, L.; Ibeas, A.; Cecín, P.** 2011. The Quality of Service desired by Public Transport Users, Transport Policy 18(1): 217-227.
8. **Chen, C.-F.; Lai, W.-T.** 2011. Behavioral Intentions of Public Transit Passengers – The Roles of Service Quality, Perceived value, Satisfaction and Involvement Transport Policy 18(2): 318-325.
9. **Friman, M.** 2010. Affective Dimensions of the Waiting Experience, Transportation Research Part F: Traffic Psychology and Behaviour 13(3): 197-205.
10. **Hilmola, O.P.** 2011. Benchmarking efficiency of public passenger transport in larger cities, Benchmarking 18(1): 23-41.
11. Ministerstvo Dopravy ČR 2015. Bílá kniha: Koncepce veřejné dopravy 2015 – 2020 s výhledem do roku 2030. [online cit.: 2017-07-22]. Available from: https://www.mdcr.cz/getattachment/Dokumenty/Verejna-doprava/Pravni-predpisy/Zelena-a-bila-kniha-koncepce-verejne-dopravy/Bila-kniha-koncepce-verejne-dopravy.pdf.aspx
12. **Becker, J.U.; Albers, S.** 2015. The limits of analyzing service quality data in public transport, Transportation 43(5): 823-842.
13. **Hensher, D.A.; Stanley, J.** 2003. Performance-based quality contracts in bus service provision, Transportation Research Part A 37(6): 519-538.
14. **Hensher, D.A.; Stopher, P.; Bullock, P.** 2003. Service quality-developing a service quality index in the provision of commercial bus contracts, Transportation Research Part A 37(6): 499-517.
15. **Sánchez Pérez, M.; Gázquez Abad, J.C.; Marín Carrillo, G.M.; Sánchez Fernández, R.** 2007. Effects of service quality dimensions on behavioural purchase intentions: a study in public-sector transport, Managing Service Quality 17(2): 134-151.
16. **Tsami, M.; Nathanail, E.** 2014. Examining travelers' "Optimal strategies" in transit trip choice, applying a classification tree approach on transit quality of Service Indicators. Kos: Springer International Publishing, 507 p.
17. **Tsami, M.; Nathanail, E.** 2017. Guidance Provision for Increasing Quality of Service of Public Transport. Riga: Procedia Engineering, 614 p.
18. **Hensher, D.A.; Houghton, E.** 2004. Performance-based quality contracts for the bus sector: delivering social and commercial value for money, Transportation Research Part B 38(2): 123-146.
19. **Dell'Olio, L.; Ibeas, A.; Cecín, P.** 2010. Modelling user perception of bus transit quality, Transport Policy 17(6): 388-397.
20. **Hensher, D.A.; Stanley, J.** 2008. Transacting under a performance-based contract: the role of negotiation and competitive tendering, Transportation Research Part A 42(9): 1143-1151.
21. **Parasuraman, A.; Zeithaml, V.A.; Berry, L.L.** 1985. A Conceptual Model of Service Quality and Its Implications for Future Research, The Journal of Marketing 49(4): 41-50.
22. **EN 13816.** 2002. Transportation – Logistics and services – Public passenger transport – Service quality definition, targeting and measurement. Brusel: CEN, 40 p.
23. **Eboli, L.; Mazzulla, G.** 2011. Performance Indicators for an Objective Measure of Public Transport Service Quality, European Transport 51(3): 1-21.
24. **Vuchic, V.R.** 2005. Urban Transit: Operations, Planning, and Economics. New Jersey: John Willey & Sons, 664 p.
25. **Paulley, N.; Balcombe, R.; Mackett, R.; Titheridge, H.; Preston, J.; Wardman, M.; Shires, J.; White, P.** 2006. The demand for public transport: The effects of fares, quality of service, income and car ownership, Transport policy 13(4): 295-306.
26. Ministerstvo Dopravy ČR 2017. Smlouva o závazku veřejné služby v drážní osobní dopravě ve veřejném zájmu na zajištění dopravních potřeb státu na období od 1.1.2010 do konce platnosti jízdního řádu pro období 2018/2019. [online cit.: 2017-08-01]. Available from: https://www.mdcr.cz/Dokumenty/Verejna-doprava/Zverejneni-smluv-na-vlaky-dalkove-dopravy-v-obdobi/Velka-smlouva-o-ZVS-na-obdobi-2010-2019
27. **Kozel, R., et al.** 2006. Moderní marketingový výzkum. Praha: Grada Publishing, 277 p.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Mobility as a Service - An Example of a New Mobility Service for Passengers on Freight Ships

F. Michelberger[1], P. Judmaier[2]

[1]*St. Poelten University of Applied Sciences, Matthias Corvinus-Straße 15, 3100 St. Poelten, Austria,*
E-mail: frank.michelberger@fhstp.ac.at
[2]*St. Poelten University of Applied Sciences, Matthias Corvinus-Straße 15, 3100 St. Poelten, Austria,*
E-mail: peter.judmaier@fhstp.ac.at

Abstract

Frequently, speed is the central requirement for a trip, which has resulted in a huge increase in air travel over the last decades. Recently, however, a growing counter-trend, in which the journey is seen as part of the holiday, can be recognized. Cruising is a booming market, but also long rail travel (Orientexpress, Transsiberian railway) are offered again. This type of travel is, however, primarily for a well-situated traveler from the age of 60, and is thus located in the luxury segment. In the research project CargoRider a platform that offers route finding and booking for cargo ships in Europe was conceptualised. The idea is to make it affordable for younger travelers, to make travel planning highly flexible and to make the travel organization entertaining. In addition, the concept builds on a sustainability paradigm, as the routes are carried out independently of the travelers, in contrast to flight and cruising flights, and no additional environmental stress is created. The study examined amongst others the extent of the interest in cargo ship travel with a younger audience and whether there are opportunities to offer it at low cost. The results showed that such a service is very interesting for the target group and is technically and legally feasible. The concept of CargoRider differs from existing offers in that it is based on the principle of flexible and agile travel arrangements known over the course of a certain period of time (Interrail) and is an excellent destination for a younger target group. The goal of the actual work is to develop the complete service design for this innovative mobility service, to create a prototypical implementation with the necessary data interfaces and then to test them for function and practicability under laboratory conditions. Both for the software product as well as the entire mobility service for freight ship travels, coordinated business models are developed. This is therefore a good example for the concept of MaaS – Mobility as a Service. The paper will present the new mobility service of CargoRider and will demonstrate how the concept of MaaS can be the basis for this innovation.
KEY WORDS: *Mobility as a Service, freight ships, web platform*

1. Introduction

Vacation and recreation is increasingly accompanied by wide travel routes. Long distances are thereby covered almost exclusively by air. Travel by ship is rare, as this almost only exist in the high-end segment. Huge floating 5-star hotels appeal to a well-heeled audience and mostly senior citizens, although young people would have time for and find adventure for a slow discovery of the world.

The project CargoRider therefore explores if a platform for passenger travel on cargo ships comparable to InterRail with rail transport can be set up, providing an alternative to air travel, especially for young people. At first the focus is on cargo ships in inland waterways. The service offered by CargoRider shall be priced to be affordable to the target group and highly flexible. To prove the feasibility of this idea, basic requirements were defined, and a prototype for a platform was set up. A market overview and an analysis of certain target groups framed the approach.

The service CargoRider is based on cooperation with shipping companies that allow certain ships to take passengers on board and on the other hand on direct agreements with shipowners. Potential passengers will find ships to book with all information and support for the planning of the trip on the platform. Hence, they can either plan a trip in advance or simply find trips and journeys. Computer-aided data analysis reduces the necessary knowledge and effort for booking. The service shall be practicable, with easy understandable visualization of information and with low technical requirements. Furthermore, CargoRider is thought to include a social media component where travel reports, experiences and adventures can be shared with the community.

2. The Market

Maritime cruise tourism has been a steadily growing business since the mid-1990s, as can be seen by the construction boom in large and very large passenger ships [8]. Since 2009, the market within the EU-28 has seen consolidation, resulting in a slight upward trend in most recent years [5]. By 2015, more than 23 million passengers have embarked on a cruise worldwide [2]. The cruise business in Germany had the following dimensions in 2015 [4]: 1.8 million passengers, 2.87 billion euros sales, 1,580 euros per person average travel price and 8.69 days average travel duration. Worldwide, the number of ferries and passenger ships is on the rise with a 5.5% increase in dead-weight tons

from 2015 to 2016. Likewise, the percentage share of dead-weight tonnage in comparison to other vessel types is growing slowly [9]. For the river, cruise organizers in Europe also registered a passenger growth of 6.7 per cent and thus numbered almost 462,000 guests. Sales are at 496 million euros [4].

A new development is the theme-driven ride with younger clientele, such as heavy metal trips. Demand is very high, tickets for the “Full Metal Cruise” 2018 were sold out within 30 minutes. This targets a younger audience, though prices do not differ from standard cruise prices (Full Meal Cruise starting from € 216 per day).

Within EU-28, passenger kilometers on the sea have been declining in the long term, but have remained constant from 2011 to 2015. At the same time, however, absolute numbers of passenger kilometers of other modes of transport have increased especially with figures for air transport within the EU-28 area being constantly on the rise. On the other hand, domestic and intra-EU-28 freight transport on inland waterways and the sea is steadily growing with sea transport having a constant share of the modal split of one-third [5].

Thus, also within Europe waterborne freight transport is playing an important role. According to “An International Classification of Ships by Type“, a passenger ship carries more than 12 fare paying passengers, which means that cargo ships can carry up to 12 fare paying passengers [6]. Freighters that are allowed to carry more than 12 passengers are defined as combination passenger-cargo ships; here regulations for passenger ships apply [7].

Thus, the number of passengers on a cargo vessel is strictly limited, which means that the boundaries for freighter travel are clearly set. Therefore, passenger travel on cargo ships is a minor niche within the passenger transport sector with estimates of 5,000 to 6,000 passengers a year [1].

Despite the negligible market share, there are travel agencies that are specialized in freighter travel [10]. In general, passenger travel on cargo ships is a successful business model. The major provider in Europe transports about 3,500 passengers a year on freight ships, with the demand, according to their words, being significantly higher. Confronted with limited supply, cabins on popular routes can fill up quickly.

The CMA CGM group reports a number of 874 passengers who have traveled on their containerships in 2013 [3]. In Europe, nine operators are currently active in this business. All of them have their individual platforms on which a trip can be booked. An independent platform does not exist.

Perhaps contrary to common belief, a cargo ship voyage is not the cheapest way to travel, the average payment is between 90 and 150 € a day [1]. This is much cheaper than a classic cruise, but luxury on the ship is also limited to basic needs, although some ships do offer a swimming pool, sauna and a small gym. As cargo ships travel at a slow pace with the average speed not exceeding 25 knots (~46 km/h) and often much lower, air travel is faster and cheaper than the cargo ship alternative, except of relocating being the journey’s purpose. Therefore, a cargo ship will hardly ever be the appropriate means of transport when the deciding factors are time and price, and neither with luxury for recreational purpose. Furthermore, a freighter cruise demands a lot of preparation, namely vaccination, medical checks, insurance and travel visa for all destinations.

Despite these detrimental facts, these journeys are labelled by travel agencies and providers as adventurous, as romantic, as unique experiences off the beaten track while sharing the seafarer’s life.

3. The Requirements

Passengers on cargo ships on inland waterways and on the sea shipping sector is an exception and is characterized by a number of peculiarities. In addition to a specific disclaimer regarding guarantees for booking requests because in maritime navigation, the captain's decision always applies, the transport conditions of shipowners and agencies are heterogeneous and require individual tests for the application. This heterogeneity refers, on the average, to the terms of carriage, the accommodation of passengers on ships, the catering rules and the rights and obligations of passengers on board. In order to be able to conclude a contract of carriage, the following categories are compulsory. Before the start of a journey or before concluding a transport contract, passengers are required to provide data (name, age, photo, address,…) and documents (health certificate,…), preferred journey area, the period of the passage, a justification for the desire for the cargo trip and a character description of the person. Documents also include ID and, where appropriate, visa. In addition, vaccination regulations must be taken into account prior to travel as well as the preparation of the payment (depending on destination, euro, dollar, etc.).

In addition, a special insurance must also be taken into account. This insurance covers deviations from the ship route, which can have a significant impact on the business of the shipping company / captain. A key aspect of this special insurance policy is that, in the case of illness, a passenger must take the necessary costs for changing the route.

In order to get information about the expectations and needs of potential users, an online survey was conducted with the following key findings:

- A majority of the respondents were particularly interested in CargoRider's service, their interest in the rating scale from 1 to 5 (1 being ‘very interested’) was rated 1 or 2.
- A strong willingness to travel with this service on the interviewees’ side is recognizable. Concerning the favored length of a trip, only 17% of participants prefer a trip longer than a month. More than 60% of those who are interested have never made a trip on a ship. The most frequent interest is sailing (55%), followed by cargo ships (46%).
- In the context of an open question, the price, the cities and the countries to be visited were classified as an important factor for planning a trip.
- Concerning the desired service on board, almost three quarters of all interviewees wanted a breakfast. The possibility to go ashore was just behind it, followed by private sanitary facilities (WC and shower). The contact with the

crew is important to more than half of the respondents, the contact with the captain is significantly less important with about 30%.

- Top destinations were London and Hamburg with about 14% of the nominations, followed by St. Petersburg and Constanta. Among the top 10 were also large sea harbors such as Marseille, Rotterdam or Gdansk.
- About 60% prefer a spontaneous organization from port to port and 40% detailed planning. The desire for detailed planning compared to a spontaneous trip was much less represented in the segment with a gross income of between 500 and 1000 € (less than 25%). Also the segment between 2000-3000 € gross income is only half as often interested in planning. There is a slightly larger number of respondents aged 30 to 49 years who are interested in spontaneous trips.
- Women's concerns about traveling on purely male-staffed freight ships are present, and more than a quarter of the answers are located on the two outer values of the five-part scale. However, almost as many respondents had absolutely no concerns in this regard. Respondents aged 20-29 years are slightly more positive than the rest of the age groups. Nevertheless, these concerns must be considered and communicated in the service design.

Furthermore a map has been sketched which, similar to the maps of subways, should be a support for travel planning (see Fig. 1). It shows the most important cities that can be reached by freight ships. In addition, an approximate travel time is given in days. This specification also takes into account different speeds in both directions in case there are, i.e. upstream and downstream. This map achieved very high levels of understandability (82% in the two upper values of the five-part scale). It can thus be assumed that the use and characteristics of the CargoRider service are well-connected.

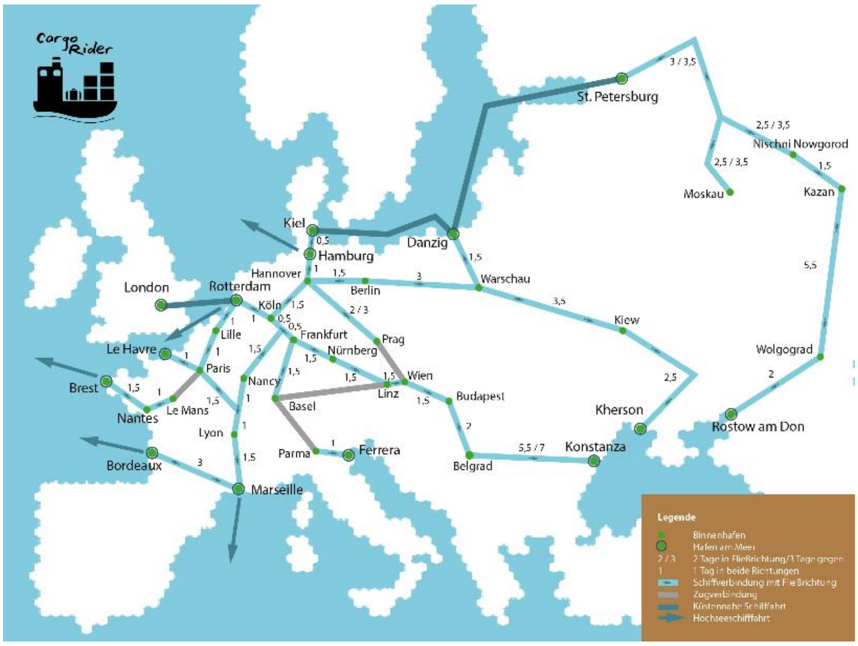


Fig. 1 Visualization of possible lines

4. The Service

Based on the requirements the service itself will be developed. In a first step, target groups were identified that might be interested in this integrated mobility service:

- Early adopters or "life style hipsters" who are looking for new travel opportunities which so far have not existed and therefore no one else could try.
- Adventure-minded people who are able to snuggle with CargoRider into a previously unknown world (experiencing the life and work of inland waterways)
- Middle-class citizens interested, for example, in ships and / or shipbuilding.
- Individual travelers who are looking for an alternative to the usual tourist river cruises, also with less comfort (cabins simpler than on inland cruisers, self-service in the cabin, etc.). This includes also travelers who want to "slow down" and travel leisurely. These are travelers who want to take their time to arrive at a certain place (time as a luxury, "luxury time travel").
- Ship enthusiasts who have always dreamed of traveling with an inland freight ship but have not yet been able to do so.
- Young, creative, flexible people in their twenties who do not need a place-bound workplace but can simply work from the laptop anywhere in the world (freelancer). This group has the advantage that they can use their travel time working.

Possible services of the platform were queried, and it has been shown that these services are mainly desired:

- Electronic deposit of tickets, e.g. bar codes (so tickets do not have to be printed).
- Electronic deposit of travel documents.
- Possibilities for online rescheduling of the trip.
- Display of the current location / map.
- Navigation function.
- Presentation of possible activities and / or sights of the cities.
- Communication with other travelers.
- Connections with other freight ships / trains including First-Mile / Last-Mile connection.

5. The Design

A user-centered design process was developed in which personas and scenarios were derived from the results of the surveys. So a conceptual design of the visual interface components of the service was conceived and evaluated again. After a re-design iteration, the design was finalized and an interactive prototype, which contains dynamic visualization elements was set up. It demonstrates the possible implementation of such a service.
The main page of the platform (see Fig. 2) is one single map that gives an overview of the rivers and the ports that are available. Information about the frequency of ships per day is provided. This is visualized by different sizing of the red spots. Also information about the frequency of ships on the river is available, which is visualized by the line width. Information can be changed according to the respective month with the time function on the bottom.

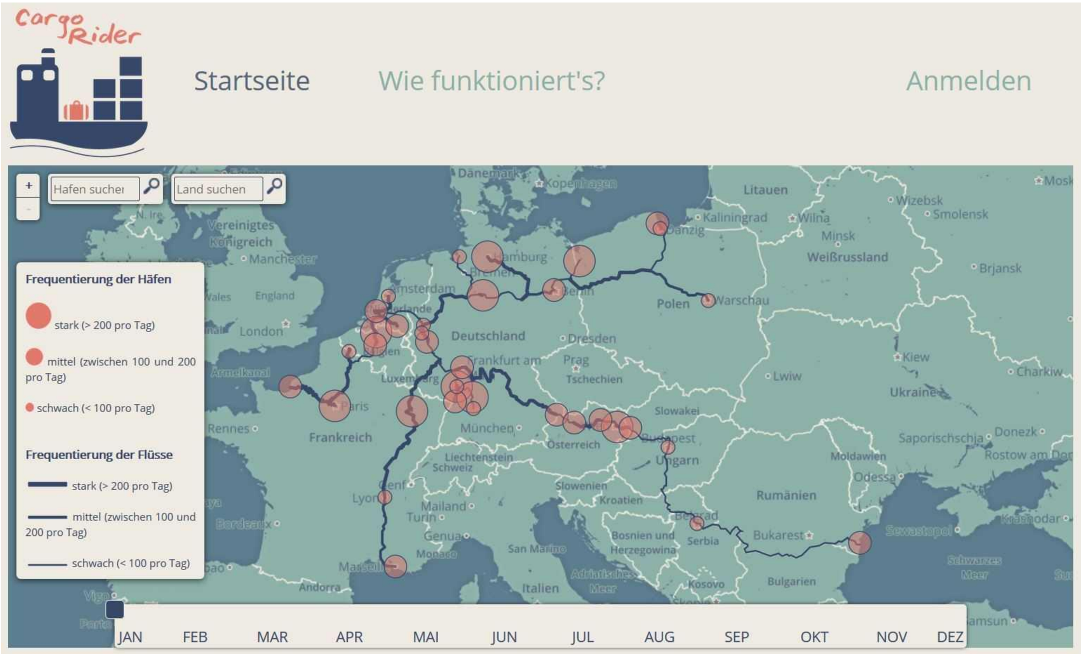


Fig. 2 CargoRider prototype

Additional features are available, like creating a profile travel diary, saving of the routes and an archive function of sent messages.

6. Conclusions

In the project CargoRider a booking platform for inland waterway journeys on cargo ships in Europe will be designed. Following the idea of MaaS – Mobility as a Service the platform is not only for the booking itself, but is also designed to fulfill the whole service that is needed for this way of travelling. In this sense, the whole process of designing the platform always has the service in mind, and is aligned with this. The principle of MaaS has proven to be a useful method to develop a comprehensive and user-friendly service.

Acknowledgements

This paper is a result of the research project CargoRider, which is funded by the Austrian Ministry for Transport, Innovation and Technology within the program “Mobility of the Future”.

References

1. **Schulz, A.; Auer, J.** 2010. Kreuzfahrten und Schiffsverkehr im Tourismus. Oldenbourg Verlag.
2. CLIA Cruise Lines International Organisation, 2016. CLIA Global Report: 23,2 Millionen Kreuzfahrtpassagiere weltweit [online cit.: 2018-04-18]. Press Release. Available from http://www.cliadeutschland.de/presse/CLIA-Global-Report-232-Millionen-Kreuzfahrtpassagiere-weltweit-49
3. CMA CGM group, 2017. Cargo Cruise: discover a new and unique travelling experience [online cit.: 2018-05-15]. Available from http://www.cma-cgm.com/products-services/cargo-cruise
4. DRV Deutscher Reise Verband, 2016. Deutsche Kreuzfahrbranche wächst auf mehr als 1,8 Mio. Passagiere [online cit.: 2018-06-11]. Available from https://www.drv.de/fachthemen/schiff/detail/deutsche-kreuzfahrtbranche-waechst-auf-mehr-als-18-mio-passagiere.html
5. Eurostat, 2017. Statistical Pocketbook 2017 [online cit.: 2018-05-28]. Available from https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2017_en
6. ISL Institute of Shipping Economics and Logistics, 2016. Shipping Statistics and Market Review Vol. 60 2016. World Merchant Fleet. ISL Institute of Shipping Economics and Logistics Bremen
7. **Showker, K.; Sehlinger, B.** 2007. The Unofficial Guide to Cruises. John Wiley & Sons, Inc.
8. **Soriano, S.** et al., 2009. Cruising in the Mediterranean: structural aspects and evolutionary trends, Maritime Policy & Management 36(3): 235-251.
9. UNCTAD, 2016. Review of Maritime Transport [online cit.: 2018-06-04]. Available from unctad.org/en/PublicationsLibrary/rmt2016_en.pdf
10. Wikitravel, 2017. Freighter travel [online cit.: 2018-05-19]. Available from https://wikitravel.org/en/Freighter_travel?title=Freighter_travel

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Social and Psychological Factors in the Work of Professional Drivers

V. Šukalová[1], P.Ceniga[2]

[1]*University of Zilina in Žilina, Univerzitna 8215/1, 01026 Žilina, Slovakia, E-mail: sukalova@fpedas.uniza.sk*
[2]*University of Zilina in Žilina, Univerzitna 8215/1, 01026 Žilina, Slovakia, E-mail: pavel.ceniga@fpedas.uniza.sk*

Abstract

The work of a professional driver is becoming ever more demanding. Besides complicated traffic factors, they are also affected by the complicated social climate, strict legislative requirements and complex working conditions; the driver's personality is strongly reflected in the work of the driver. The safety factor is particularly important for driver's work, expressing the objective state or subjective belief of the individual about the condition of the conditions that ensure the protection of his physical, social, psychological integrity from negative consequences such as damage, failure. Psychosocial risks are related to the negative psychological, physical and social influences that arise from the specificities of the organization of the driver's work, management, as well as the demands of social conditions, including excessive work demands, time demands, contradictory demands on work performance, inconsistency of job requirements and skills employee, work alone, insufficient employer support, and so on. The article focuses on the analysis of specific social and psychological factors in driver's work, psychosocial risks and their impact on driver satisfaction as the basis for managerial work.

KEY WORDS: *Social factors, psychological factors, driver, work*

1. Introduction

The transport system has many components (rail, road and air infrastructure vehicles) in which many actors (haulage companies, public transport providers, infrastructure planners, transport consumers) can act within certain limits of freedom (economics, traffic law and transport regulations). Mobility and traffic generate economic value and social well-being; they also have harmful consequences on the health, the existence and the destiny of people as on the natural environment. Reducing harmful effects of traffic and preserving its advantages requires serious control and organization. Among social sciences, psychology is, essentially, the instrument of knowledge of the "human factor," and, more precisely, of man in action; this is why, since the beginning of 20th century, psychology was brought to study drivers abilities and mental structures. Work in transport affects the life of society, so the social aspects of their work are also important. Work in general transport (road, rail, air, and water) places special demands on employees. One of these is aspects of working time organization which rarely correspond to regular working hours. Specificities of work and conditions of work, for example, road transport are also documented by frequent changes to social legislation in the field of road transport adopted by the European Union. Drivers of passenger and freight transport must meet increasingly demanding requirements arising from developments in the transport market within the European Community. In order for drivers to maintain their knowledge, current drivers should be subject to the obligation to undergo regular training to restore their skills and experience important for the performance of their profession. In addition, new drivers should demonstrate basic qualifications similar to other professions. Social legislation for road drivers is one of the most important legal areas for road transport operators. Proper adherence to social regulations provides for individual transport companies not only certainty that they will not be sanctioned by control bodies but also aim to prevent traffic accidents due to lack of concentration and fatigue of drivers due to overloading their physical and psychological forces. The minimum requirements for basic qualification and regular training concern the safety rules to be observed when driving and when the vehicle is stationary; development of defensive style of driving - anticipating danger and taking into consideration other road users. Also, the psychological competence of professional drivers is important.

2. Psychosocial Factors and Risks in the Work of a Professional Driver

Significant changes that have occurred in the world of work over the past decades have also created new risks to health and safety. These changes brought new psychosocial risks, in addition to physical, biological and chemical risks. Work-related risks have been identified as one of the most important challenges for health and safety. It is related to workplace problems, such as stress related to work and workplace violence, harassment and bullying. In addition, it appears that stress is related to deterioration in performance, increased absenteeism and accidents. Excessive stress threatens the health of employees and prevents a person from coping with any other claims. Psychosocial according to the most widespread definition means "interaction between psychological and social factors". It means interaction in both directions, from social factors to mental and vice versa. Psychosocial risks can be defined as those aspects of work design and organization and management of work and their social and environmental contexts that can potentially cause

psychological, social or physical harm. In addition, traffic is busier and motorways do not, drivers are also affected by a complicated social climate and complicated working conditions. Over the years, they are also learning defensive, more responsive driving. Driving is a fairly simple activity, but the driver's personality reflects in this activity and, accordingly, is in the traffic management. Safer and better cars make it easier to ride and increase the feeling of safety and security on the road. They can drive at a higher speed. I can handle more difficult terrain. The main factor of the violation (of course, if the driver is not deceived or less experienced) and the unscrupulous driving is always the personality and social level of the driver. Correct evaluation of situations affects, in addition to experience, the level of the innate intellect, that is to say, the healthy sedentary intellect and the ability to interact with other road users. Life on the road with all its consequences and consequences works like a triangle: the driver - the road - the car. The main cause of traffic accidents is a driver who often fails to cope with the increase in traffic density and increasingly efficient cars. During the last period, the vehicle has been greatly restored park, added new kilometres of motorways and express roads, increased traffic density, but the education curriculum almost completely dropped out of the curriculum. Significant impact on the emergence of risks is also the fact that the boundaries between being at work and at work are becoming increasingly blurred, making it more difficult to achieve work-life balance (i.e. reconciling work, family, and social life). The tensions created by working under such conditions may result in the exposure of employees to psychosocial risks, which may, in turn, have an impact on physical, psychological and social health [1]. The activity of the driver is characterized, among other things, by controlling or operative provision of the operation of the equipment or of the trucking processes (the truck is the equipment and the driver ensures its operation, it also has to make operational decisions in the course of the road, in search of companies, navigation, etc.); drivers have in individual EU countries a logical problem with communication, yet it is not conceivable to manage all the languages of Europe and those that are worrying about arranging the place and the burden of loading and unloading in individual companies, catering, hygiene, etc.) with a potential responsibility for health and the safety of other persons (directly responsible for the health and life of their colleague in the cabin, e.g. in the case of handling the goods, for example faults, accidents, etc.) or for removable damage (in the event of an accident, the truck can be damaged for several million crowns, also goods of similar value, vehicles, roads and their facilities, etc.). The main physical hazards and risks include: exposure to vibration and long sitting (seat shape, cab design and other equipment), manual handling, noise exposure - when loading and unloading, truck driving (engines, tires, fan, etc.) (exhaust gases, chemical substances on board, fuel, exposure to road dust during loading, unloading and resting, washing and preparing the vehicle), climatic conditions (heat, cold, drought, rain, etc.) , the limited scope of adjustments to ergonomic working conditions and a healthy lifestyle. It is necessary to identify psychosocial aspects and risks of driver´s work to be able to manage them according to new trends in era of globalization.

2.1. Psychological Requirements for Driver´s Work

Every professional driver must have a valid psychological test. Drivers less than 50 years of age may not have an examination older than 5 years, and after fifty years the test must be repeated every two years. Testing focuses on intelligence, memory, attention, responsiveness, attention to stress, and aspirations. Personal qualities such as emotional stability, aggression, willingness to risk other characteristics of the personality are also important. Testing is usually sent by a driver's employer if they become involved in a serious traffic accident - then it is investigated whether their evil mental state could be involved. The worsening mental state may be a temporary disposition - for example, high temperatures, personal problems, a long-lasting illness that shows irritability to aggression (for example, diabetes), but also dementia or other mental illness.

Driving a motor vehicle is a demanding and complex activity requiring constant readiness and responsiveness of the organism to incoming stimuli, which can occur at a conscious and unconscious level and is dependent on several variables. From driver skills, skills, experience from a variety of cognitive determinants to receive and process information from the outside and the inner world. In transport psychology, it is mainly about perception, attention, memory and decision making. Also emotions and moods and various personality variables such as temperament, motivation, attitudes, values and interests are also important. In addition to cognitive and personality variables, the driver's psychomotor, flexibility, coordination of movements and the speed and accuracy of driving responsiveness play an important role.

The essential characteristics of the driver needed to drive a motor vehicle are:

- Perceptive, perceptive, visual, auditory, kinaesthetic, concentration, spatial orientation;
- Psychomotor skills - speed and accuracy of responses, coordination of movement, flexibility;
- Intellectual abilities - cognition, logical, analytical, practical and critical thinking, visual memory, etc. [2]

Skills express a wide range of assumptions needed to successfully perform certain activities and skills. They are developed on the basis of innate dispositions (waves), through learning (social learning, classroom education, or training). By default, skills are divided into general abilities - intelligence and special abilities, including verbal, numerical, memory, psychomotor and artistic abilities, spatial imagination, perceptual alertness. In order to be able to perform successfully, we must achieve a degree of intellectual ability. For drivers without increased responsibility, the minimum IQ 70 (or 16 percentile) is set, for drivers with increased responsibility = IQ 85 (33 percentile). In the test, in addition to the general intelligence of the components, the logical and analytical considerations, concentration, perception, spatial orientation, attention, psychomotor coordination, speed and accuracy of response, reaction time, and so on, come to the fore.

Accident affection

Accidental affection is a function of human abilities; it is relative ability or inability to adapt to the requirements of the traffic situation, whether these requirements are already put on the ability of people or their psychic, physical or social capacity for this role. The extent to which they are capable to cope with the situation and the adequacy of their adjustment will depend on the match of the whole complex of factors in the individual, many of which are changes throughout his life. Accidental affection of an individual in any one the moment therefore appears to reflect his ability or inability to remain in a balance between these factors. [3]

Perception

Perception or perception ensures the reception and processing of information through the sensory system, which provides us with the basis for interacting with our environment. Perception occurs at a time when the object perceived in some way reflects the properties of the surrounding world. [4]

Work load

Attention

Attention of the driver is one of the main factors of safe traffic. Attention is a condition of every conscious human activity. Concentration of our attention threatens us inexperience, emotions, ideas, tension, fatigue, stress, lack of sleep, weather, mood, alcohol, drugs, smoking, drugs, It is also necessary to realize that attention is influenced, among other things, by the daily rhythm. The driver is considerably narrower and considerably broad is unsuitable. Is a necessary for the driver to constantly concentrate and distribute during the journey attention, adapted to current traffic conditions. [5]

Memory

Memory is actually the ability of a man to remember, to preserve and to equip what he perceived, experienced, and did in the past. There is more species memory, the most common is the distribution according to the nature of the psychic activity prevailing activity. The storage properties include, in particular, the width (memory capacity) of the memory speed and accuracy of remembering, the ability to retain knowledge in memory and its readiness.

Emotional intelligence

Every profession, not excluding driving, requires a specific structure practical intelligence, including practical and social components, visual memory, optical point of view, revelation of relationships between things, logical, analytical and critical thinking. An important role in the driver's work also plays emotional intelligence, which is in Slovakia in psychological examinations drivers do not pay attention. Havlík (2005) under the term emotional intelligence means:

1. Ability to regulate and control emotional states;
2. Self-knowledge;
3. The rational use of emotional energy;
4. Imprisonment into the behaviour and thinking of other road users;
5. Know how to read the emotions of others, to have a positive relationship with each other and others;
6. Retain negative emotions. [2]

The term *work engagement* expresses an active personal involvement in any work matter, a particular story, phenomenon or process, prominent energy, vitality, positive emotional accompaniment, active co-operation to solve the problem; willingness and ability to contribute to society's success; psychological devotion, initiating your work, and making your organization useful. In working life, engagement is shown as an important factor affecting work attitudes, behaviour, and employee outcomes. [6] A similar notion of engagement is *commitment to work and organization*. [7] Both concepts include loyalty and voluntary commitment (the desire to remain a member of the organization, accepting its goals and values, making efforts to the benefit of the organization).

2.2. Psychological risks

It´s necessary to identify the most serious psychological risks connected with the work of driver:

Work load

While driving, the driver is subject to a certain psychological burden, the management of which depends on the overall ability to handle the stress and the degree of stress tolerance. Resistance to mental stress in traffic psychology means the ability to process and to cope with the demands and influences of the transport environment. Workload changes include: increased use of new technologies such as remote planning and monitoring tools, on board computers for reporting and recording delivery of goods, the need for knowledge of traffic regulations and foreign languages in EU countries. On the other hand, such work is more monotonous and provides fewer learning opportunities than the average, economically active population.

Fatigue

Fatigue is avoided; mostly it comes slowly and unexpectedly. However, its action often has fatal consequences. Traffic psychology distinguishes between 4 types of fatigue: physical (resulting from vehicle management), fatigue and weakening of the nervous reflexes, sensory fatigue (most often refers to vision and manifests with reduced sharpness, weakened central and peripheral vision, etc.) and fatigue of psychological processes , concentration, attention). Psychological fatigue is defined as a subjectively experienced disinclination to continue performing the task at hand. It generally impairs human efficiency when individuals continue working after they have become aware of their fatigue.

Violence and harassment

Violence and harassmentare on the upward trend in transport, but are largely unannounced. Traffickers often have to act as intermediaries for organizational changes affecting the customer service.

Burnout in the Field of Professional Driving

Burnout is a psychological syndrome, which increases as a response to the chronic exposure to work-related stressors. Theoretically, burnout includes 3 main components: Emotional exhaustion, or the feeling of emotional overwhelming at work, cynicism (also known as depersonalization or disengagement), defined as detachment from others or indifference at work, and reduced professional efficacy (also referred to as professional accomplishment), which is the tendency to evaluate one's efforts and achievements in a negative manner. [8, 9] Burnout is associated with negative health outcomes such as anxiety, depression, sleep disturbances, headache, gastrointestinal disease, hypertension, muscle tension, and chronic fatigue, and especially in the case of professional drivers, with poor job performance.

Stress

Big technological and economic changes together with great competition are constantly pushing for a change of lifestyle. Also drivers need high flexibility and adaptability to new technological and process solutions also in transport. Rita Atkinson (2003), describes stress as a state when people meet events, which they perceive as threatening their physical or mental well-being. These events are So-called stressors and human responses to stress reactions are so-called stress reactions. [10]It should be said that people's response to stressors varies greatly. Where some individuals can in case of exposure to a stressful situation show severe psychological or physical problems, others take a stressful event as a motivation and challenge. In particular, stressors associated with work in an organization are reported by Dědina and Odcházel (2007, p.44): Inappropriate working environment, Incorrect work design, Bad management style, Bad relationships in the workplace, uncertain future, contradictions in the interests of the organization and the individual. [11]

Physical inactivity, work intensification, and work-life balance are very prevalent emerging OSH risks, often with a long exposure duration, but their effects are estimated as of medium importance. In some specific target groups, such as the bottom of the labour market where workers are exposed to multiple risks, the effects can be considered of high importance.

Job insecurity is considered an emerging risk, but the different research groups estimate the number of exposed workers differently.

For multiple risks, however, only the number of exposed workers could be estimated. What makes this difficult is the large diversity of risk combinations. It appears that the combination of psychosocial and physical stressors occurs often, and when it occurs the exposure duration is long but may show a low to intermediate interactive effect. The effects are likely to be ill health, i.e. musculoskeletal and mental health problems, cardiovascular disease, and absenteeism. Dropping out of work is likely to include early disablement for work. Other important determinants affecting driving safety include age (at least people aged between 35 and 45 years of age), health status, medication, stimulant or narcotics (alcohol, coffee, drugs, cigarettes, etc.) [2] It follows that in traffic situations we can act responsibly, that is, have reasonable responses (thinking, behaviour, negotiation) to a given traffic situation, or inappropriate when it can be an instinctive short-circuit response (e.g. braking in a situation where it would be better to avoid a dangerous situation by adding gas and acceleration or respond to an unexpected situation covering your eyes with your hands instead of holding the steering wheel and checking the situation.

3. Social Requirements and Regulations at the Driver's Job

Social area of drivers work is regulated by:

- Regulation of the European Parliament and of the Council (EC) 561/2006 on the harmonization of certain social legislation relating to road transport - the working regime for crews of road freight vehicles;
- Regulation of the European Parliament and of the Council (EC) 165/2014 on tachographs in road transport;
- European Agreement on the Work of Crews of Vehicles in International Road Transport (AETR Agreement;
- Act no. 462/2007 Coll. on the organization of working time in transport.

3.1. Finding Violations in the Social Field

Non-compliance of drivers work with social regulations has a negative impact on society and poses serious risks. In 2016, 10,122 drivers were surveyed by workplace inspectors and land-based inspectors. The number of days checked (record sheets and days downloaded from digital tachographs) is 308,602 days, or 122.5% of the total planned number of driver days checked for 2016 (252,000 working days of drivers).

In the workplace, 3,184 drivers were checked by work inspectors in 2016. 183 460 working days were checked, which is 59.5% of the total number of drivers checked in 2016.

On the roads, 6,938 drivers were checked in 2016. 125,142 working days were checked, 40.5% of the total number of drivers checked in 2016. In assessing the deficiencies identified by labor inspectors at roadside inspections and in road transport inspections, we can see that the situation has improved slightly again in comparison with 2015. Checks carried out within the task identified a total of 12,227 shortcomings, with 308,602 working days checked, representing a drawback of 25.1 working days checked. In a task with the same focus in 2015, there was one shortage of

21.7 checked drivers' working days. Summary of the most frequent shortcomings of drivers for 2016 found during roadside inspections and workplaces together:

– - Drivers did not observe the daily minimum rest time (4 340);

– - Drivers have exceeded the lead times of 4.5 hours, after which the break should have been followed, + have not kept the breaks for daily driving for a minimum of 45 minutes (4 079);

– - Drivers exceeded the daily driving times (1,652);

– - Drivers did not observe the weekly minimum rest time (871);

– - Drivers did not submit the record sheets or Outputs over the previous 28 days (562);

– - Drivers exceeded the two week driving time limit (363) [12].

The most important deficiencies found unauthorized handling of tachographs in order to deactivate the tachograph; driving a driver other than his own tachograph card, employers have not ensured regular downloading of driver card data and data from vehicle units, and they did not keep the record sheets used during the prescribed time.

The number of deficiencies is decreasing slightly each year due to several factors: the gradual increase in the legal awareness of drivers and employers themselves, the preventive activity of labor inspectorates in the previous period, the constantly increasing quality of driver checks not only in Slovakia but also abroad, the related inclusion of better drivers for work and, last but not least, by increasing the number of vehicles equipped with a digital tachograph. While in 2015, vehicles equipped with digital tachographs accounted for 79.4% of all checked vehicles at roadside inspections; in 2016 it was already 85.3%. The number of digital tachographs has been steadily rising since their introduction into practice in 2006. With digital tachographs, all data are recorded in detail on the driver card as well as in the tachograph itself, and therefore the possibility of their concealing is reduced significantly data distortion. For this reason, drivers are even more motivated to comply with the rules of social legislation in transport.

3.2. Safety and Work Satisfaction

Work safety is very important element of the satisfaction. Lack of employee satisfaction leads to their working lethargy and demotivation. At the same time, it is not possible uniformly to define certain employee satisfaction criteria for all enterprises. Each company has its specific features that affect the satisfaction of its employees. Uniform measures would not produce the desired results in this case. Safety is an expression of the objective state or subjective belief of the individual about the condition of the conditions that ensure the protection of its physical, social, psychological integrity from negative consequences such as harm, accident, error, failure. [13] The sense of security we can understand as an emotional state during which one perceives that there is no immediate risk of psychological or physical harm. Road transport is one of the most dangerous sectors in the EU. CARE European accident statistics show that approximately 10,000 people per year die in Europe in traffic accidents. This data includes an average of 1,300 drivers of urban and long-distance buses, heavy goods vehicles and trucks (i.e. vehicles up to 3.5 t). Increased risk in road transport also contributes to the development of this sector and the associated change in workload. Driver work involves a higher degree of use of new technologies such as remote planning and monitoring tools, onboard computers for reporting and recording delivery of goods, the need for knowledge of traffic regulations and foreign languages in EU countries. On the other hand, such work is more monotonous and provides fewer opportunities for education than the average economically active population. The philosophy of risk assessment is based on the principle that achieving the required level of safety at the workplace can only be preventive by assessing what can harm the health of employees. The obligation to assess risks is laid down in the Occupational Health and Safety Law as one of the employer's basic obligations in this area. Promoting health at work requires a holistic approach all initiatives should be prepared with regard to the private life of employees, their working lives and mutual interactions between them. It is known that working conditions affect the overall health of employees, for example, that sedentary work can contribute to obesity. Likewise, their personal habits, attitudes, and lifestyles affect their employees' health and well-being, which can also affect their work performance. Workplace health protection can be defined as "a joint effort of employers, employees and companies to improve the health and well-being of people at work. This improvement can be achieved by improving the organization of work and the working environment, promoting active participation of employees in health activities and promoting personal development.

4. Conclusions

Promoting workplace health protection involves introducing measures that promote behaviour and attitudes to health, support mental health and well-being, as well as a work-life balance, and address work-related, aging and development issues. A specific combination of risks and a combination of factors such as ergonomic risks, labour-related stressors, noise, hazardous substances, vibration, unusual working time, work from home and work, lack of facilities, difficult working conditions, need for constant adaptation, and many the structural changes that have taken place in this sector are a particular challenge for monitoring and prevention. Workplace health interventions to improve the health and well-being of drivers, a range of interventions can be made in the area of health promotion. Workplace health promotion planning and relevant interventions should, whenever possible, be linked to risk prevention activities. In the road transport sector, it is important, as in any other sector, to pay attention to working conditions to ensure qualified and motivated employees. Compared to other sectors, however, certain characteristics of this sector make it

difficult to manage risk management. Based on risk assessments and risk assessments, it is possible to identify the most serious risks. Some risks can be avoided by employer measures. Other risks are difficult to prevent, but it may be possible to influence and influence the degree of risk (probability) and severity (effect). Preventive measures are the following: clear guidelines, a balanced division of workloads, employee impact, information, clear procedures and guidelines, and responsibilities associated with competencies. A comprehensive solution for sustainable driver work is at present adopting the Corporate Social Responsibility concept at the corporate level. Promoting Corporate Social Responsibility with respect to emerging OSH risks Transport Companies should increasingly adopt the concept of responsible business practices. This means not only integrating social and environmental concerns in business practices; Safety and Health at Work is increasingly seen as an important dimension of CSR. CSR is strategic tool, which offers also opportunities for psychosocial risk management. It´s is a new approach in human resources management and new competence of transport managers that needs to be taught.

Acknowledgement

The paper is an output of the project:

VEGA 1/0696/16 Design of methodology for measuring quality of life in a regional context.

VEGA 1/0244/16 Personnel marketing as a new approach of the ensuring and maintaining the skilled workforce in Slovak companies.

References

1. **Taylor, A.H.; Dorn, L.** 2006. Stress, fatigue, health, and risk of road traffic accidents among professional drivers: The contribution of physical inactivity, Annu Rev Public Health 27: 371-391.
2. **Havlík, K.** 2005. Psychologie pro řidiče. Portál, s.r.o., Praha.
3. **Shaw, L.; Sichel, H.S.** 1971. Accident Proneness. Pergamon Press, Oxford – New York.
4. **Stenberg, R.J.** 2002. Kognitivní psychologie. Praha: Portál.
5. **Šucha, M.; Rehnová, V.; Kořán, M.; Černochová, D.** 2013. Dopravní psychologie pro praxi. Grada Publishing, a.s., Praha.
6. **Yalabik, Z.Y.; Popaitoon, P.; Chowne J.A. & Rayton, B.A.** 2013. Work engagement as a mediator between employee attitudes and outcomes, The International Journal of Human Resource Management 24(14): 2799-2823.
7. **Bláha, J. et al**. 2004. Pokročilé řízení lidských zdrojů. Brno: Edika.
8. **Maslach, C.** 2009. Comprendiendo el Burnout, Cienc Trab 11: 37-43.
9. **Taris, T.W.; Schreurs, P.J.; Schaufeli, W.B.** 1999. Construct validity of the Maslach Burnout Inventory - General Survey: A two-sample examination on its factor structure and correlates, Work Stress 13: 223-237.
10. **Atkinson, R. et al**. 2003. Psychologie, Praha: Portál s.r.o.
11. **Dědina, J.; Odcházel, J.** 2007. Management a moderní organizování firmy, Praha: Grada Publishing, a.s.
12. Report on the state of work protection and on the activities of the state administration bodies in the area of labor inspection in 2016, the National Labor Inspectorate, [online cit.: 2018-02-22]. Available from: https://www.ip.gov.sk/wp-content/uploads/2017/11/Priloha1-1.pdf
13. **Jex, S**. 2002. Organizational Psychology, a Scientist-practitioner Approach, New York: John Wily & Sons, Inc. 2002.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

A Method of Vehicle Classification Using Neural Networks

W. Loga[1], K. Brzozowski[2], A. Ryguła[3]

[1]*University of Bielsko-Biala, Willowa 2, 43-309, Bielsko-Biała, Poland, E-mail: wloga@ath.eu*
[2]*University of Bielsko-Biala, Willowa 2, 43-309, Bielsko-Biała, Poland, E-mail: kbrzozowski@ath.eu*
[3]*University of Bielsko-Biala, Willowa 2, 43-309, Bielsko-Biała, Poland, E-mail: arygula@ath.eu*

Abstract

Article presents a vehicle classification method using neural network. The method was created and used for data registered by weigh-in-motion (WIM) systems. Within analysis the data from weighing stations located on national Polish road network was used. Authors selected measuring points equipped in technologically diverse weight sensors. The research includes among others WIM stations based on quartz sensors, load-cell platforms and strain gauge strips. The purpose of the study was to evaluate the effectiveness of developed method and comparison of presented concept with other methods that are currently used in automatic vehicle type recognition. Presented research considers vehicle classification according to European TLS 2012 8+1 standard.
KEY WORDS: *vehicle classification, weigh-in-motion, WIM*

1. Introduction

Traffic engineers are increasingly searching for faster, more effective in-motion vehicle recognition and classification solutions. Accurate traffic flow characteristics are essential tool for adequate road and infrastructure maintenance. Collecting traffic structure data in a continuous mode allows conducting short and long-term vehicle parameter analyses. Solid and up-to-date information ensures urban mobility, valid traffic organisation and road network development planning adjusted to ingrowing traffic load [1, 2].

Modern vehicle classification methods can be divided by the selected approach (the dimensions of the vehicle and axle configuration or other qualifiers, such as the noise level and the induced substrate vibration level [3]). Intelligent Transportation Systems development resulted in Weigh-in-Motion (WIM) technology becoming the elementary tool for collecting and assessment of vehicles parameters data. Weigh-In-Motion systems combine a number of measuring, control and communication devices. System components may be divided into two essential parts. The first one is overrun section, usually permanently connected with road surface. The second part are measuring and recording instruments. The relevant elements of WIM station are the inductive loops, which allow among others to measure vehicle magnetic length and vehicle speed. Measuring system is complemented with ANPR cameras and height sensors.

The key part of weigh-in-motion systems is the measurement accuracy class. European widely used vehicle categorization standards are COST 323 [4] and TLS 8+1 specification [5]. WIM systems use qualifiers similar to the manual classification method. It is based on combined axle configuration and dimensions of vehicle. The solution enables to classify vehicles in 13 different classes, based both on COST 323 and TLS 8+1 standard.

As the research dataset authors selected data collected from a standard Polish WIM systems with a B+(7) weighing class accuracy. The described datasets classify vehicles according to TLS 8+1 specification as it obtain higher overall efficiency rate (comparing to COST 323) exceeding 90%. High TLS 8+1 standard efficiency level is demanded by Polish General Directorate for National Roads and Motorways [5]. This A1 standard results from the specification TLS 2012 developed by German Federal Highway Research Institute (BASt).

Considering various solutions of measurement technology used within the WIM station, classification methods diversity and market high demands in a field of effective vehicle recognition, it is advisable to search for a universal classification method. The universal method should be based on the basic vehicle parameters that can be measured by any WIM stations, where the high measuring accuracy is required. The example of such method using discriminant analysis was presented in [3], now authors propose a solution based on artificial neural network.

2. Neural Networks

For vehicle classification an artificial feed-forward multi-layer neural network was proposed. The network has seven inputs signal, two hidden layers and one neuron on the output layer as presented in Fig. 1.

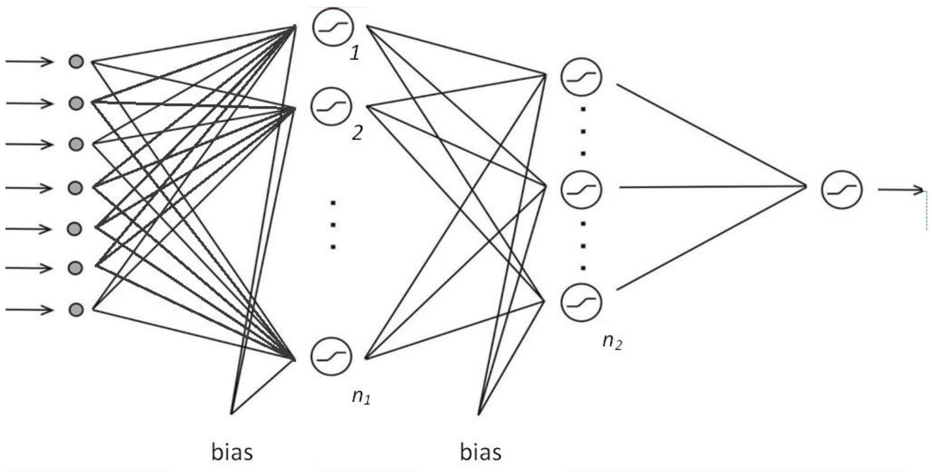


Fig. 1 Schema of the architecture of the feed-forward multi-layer neural network used in this study [own study]

As the inputs signals where chosen only those parameters where is required high accuracy of measurement by WIM system. The data contain following information:

- number of axles;
- vehicle length;
- first axle load;
- axle group;
- first axle space;
- minimum space between axles;
- maximum space between axles.

After some preliminary tests the network architecture of 7-7-12-1 was applied. It means that there are 7 neurons on the first hidden layer, and 12 neurons on the second hidden layer. The activation function of neurons was a bipolar function in the form:

$$f\left(w^t z\right) = 2\left[1 + e^{-\lambda w^t z}\right]^{-1} - 1\,, \tag{1}$$

where w – vector of weight used for neuron input signals; z – vector of neuron input signal; λ – coefficient defining the range of linearity.

For the network learning the momentum method was used with incremental updating of weights [6]:

$$w^{(n+1)} = w^{(n)} - \eta^{(n)} \nabla\Omega\left(w^{(n)}\right) + \delta\left(w^{(n)} - w^{(n-1)}\right), \tag{2}$$

where η – learning coefficient; Ω – mean square error of network's response relative to the values expected for a given input signals; δ – coefficient.

Simultaneously in each step learning coefficient has been modified according to formula [6]:

$$\eta^{(n+1)} = \begin{cases} 0.7\eta^{(n)} & \text{for} \quad \Omega^{(n)}\left(\Omega^{(n-1)}\right)^{-1} > 1.06 \\ 1.15\eta^{(n)} & \text{otherwise} \end{cases} \tag{3}$$

Taking into account a last hidden layer of the network with k elements, the value of the vehicle category is calculated as:

$$\text{Category} = \text{round}\ f\left(\sum_{i=1}^{k} w_i \cdot z_i\right). \tag{4}$$

The learning of the network was performed until the network reaches an error of classification below 5% for the entire learning set. The range of variability of the individual parameters constituting the input signals in learning set is shown in Table 1.

Table 1

Characteristic of the input signals in training set [own study]

Input parameter	Min	Max	Average	Median
Number of axles	2	6	-	-
Length [cm]	90	2080	1002,42	900
First axle load [kg]	20	9233	3126,30	2660
Axle Group	0	3	-	-
Min. axle space [cm]	65	691	292,26	260
Max. axle space[cm]	135	830	432,99	432
First axle load [kg]	135	713	385,31	371,5

In the learning process a random determination of training patterns was used. Finally after more than 1600 training epocs the error of classification reached value below 5% - Fig. 2.

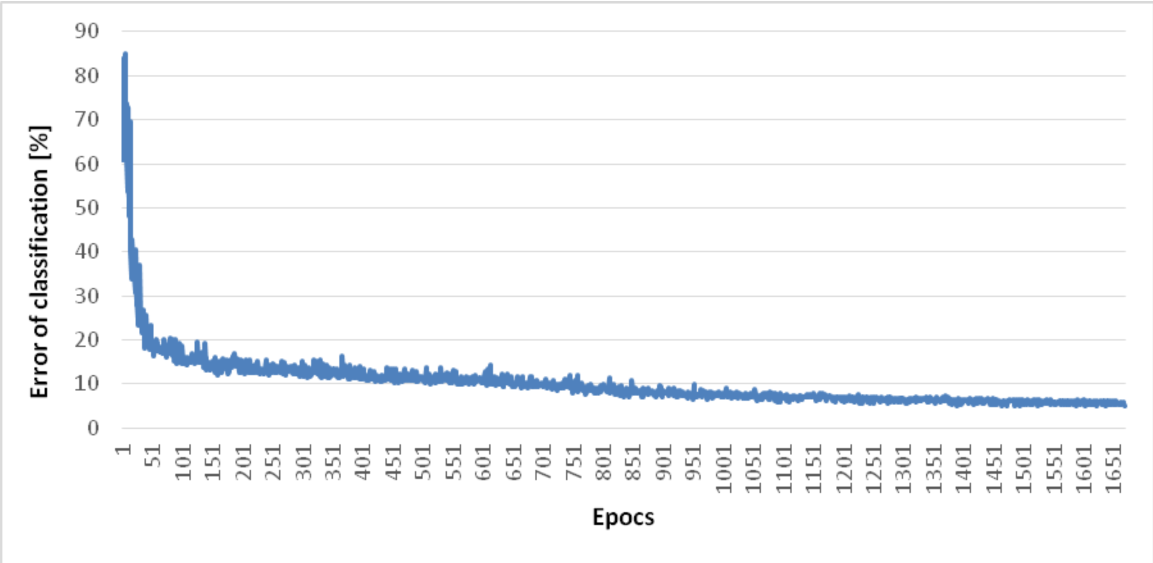


Fig. 2 Change of the network error during learning process [own study]

Presented neural network complied expected effectiveness level for most of vehicle categories. The accuracy results were presented in Table 2. The only vehicle class that did not meet the demanded expectations according to Polish standards was the 9th vehicle category (Articulated lorry) with the classification accuracy of 92%. The classification imperfection was only 3% below the demanded standard for sample size of 103 vehicles. It is worth mentioning that the accuracy level obtained for the other classes exceeded the imposed requirements.

Table 2

Learning data set classification efficiency rate [own study]

Category (8+1)	Samples	Efficiency rate
10	89	97%
7	97	99%
11	91	99%
2	100	100%
3	96	100%
8	103	96%
9	113	92%
5	101	99%

Finally, the efficiency of vehicle classification using neural network was verified for a new set of data. The range of variability of the individual parameters constituting the input signals in verification set is shown in Table 3.

Table 3
Characteristic of the input signals in data set used for verification [own study]

Input parameter	Min	Max	Average	Median
Number of axles	2	6	2,89	2
Length [cm]	50	2070	1004,92	885
First axle load [kg]	12	9173	3119,31	2616,5
Axle Group	0	3	0,88	0
Min. axle space [cm]	60	692	295,53	262
Max. axle space[cm]	138	901	435,41	433,5
First axle load [kg]	138	730	385,76	380

Total classification error obtained for validation set was below 5%, by analogy to the training set. The performance of classification for each vehicle class was presented in Table 4.

Table 4
Verification data set classification efficiency rate [own study]

Category (8+1)	Samples	Efficiency rate
10	87	100%
7	99	98%
11	100	87%
2	100	100%
3	100	85%
8	103	99%
9	105	96%
5	100	96%

Discussing the validation set the classification effectiveness for 9th vehicle category met the imposed demands (>95%). However, the result of analysis for lorries (category 3) and VAN vehicles (category 11) didn't comply with TLS A1 precision requirements (>90%). In the case of category 3 misclassification, the vehicles were mainly confused with buses and vans.

3. Conclusion

Summing up, the proposed classification method using the neural network demonstrated high effectiveness for analysed data set. The average precision of classification was 95% and reached 100% efficiency rate for category 10 (car) and category 2 (car with trailer). However, employing the presented method in the TLS A1 accuracy standard systems requires improving the performance of lorry, lorry with trailer and VAN classification. The important part of future work will also play the increased testing set sample size and conducting further validation tests. Authors will also consider a use of two-stage procedure similar as proposed in paper [3].

References

1. **Ryguła, A.; Loga, W.; Brzozowski, K.** 2015. Estymacja napełnienia pojazdów komunikacji zbiorowej z wykorzystaniem preselekcyjnych systemów ważenia pojazdów, TTS Technika Transportu Szynowego 12: 1341-1344.
2. **Loga, W.; Mikulski, J.** 2016. Traffic Analysis Based on Weigh-In-Motion System Data, Challenge of Transport Telematics, Springer s. 268-279
3. **Ryguła, A.; Brzozowski, K.; Maczyński, A.; Konior, A.** 2016. A Method of Vehicle Classification Using Discriminant Analysis, Archives of Transport System Telematics 10: 28-31.
4. **Jacob, B.; O'Brien, E.; Jehaes, S.** COST 3232 Weigh-in-Motion of Road Vehicles, access 15.05.2018 http://www.is-wim.org/doc/wim_eu_specs_cost323.pdf
5. Polish General Directorate for National Roads and Motorways: Test stanowiska ważenia pojazdów w ruchu sprawdzający poziom detekcji, identyfikacji i klasyfikacji pojazdów. Access: 15.05.2018 https://www.gddkia.gov.pl/pl/d/fb7df1c694591d8c696ce799c4ed6b68
6. **Osowski, S.** Sieci neuronowe w ujęciu algorytmicznym, WNT, Warszawa 1996

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Basic Principles of Critical Infrastructure Protection

J. Štoller[1], P. Dvořák[2], T. Túró[3], E. Zezulová[4]

[1]*University of Defence, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: jiri.stoller@unob.cz*
[2]*University of Defence, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: petr.dvorak@unob.cz*
[3]*University of Defence, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: tomas.turo@unob.cz*
[4]*University of Defence, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: eva.zezulova@unob.cz*

Abstract

The article deals with basic principles of critical infrastructure protection in transport engineering and energy engineering. It describes the classification of critical infrastructure objects. The paper is the output of basic and applied research of the Department of Engineer Technology of the University of Defence in Brno and the Military Research Institute in Brno.
KEY WORDS: *basic protection principles, transport engineering, energy engineering, critical infrastructure*

1. Introduction

After a longer period of relative safety, Europe faces a deteriorating security situation. The security situation in all aspects, including the military aspect, has dramatically worsened in recent years on the periphery of Europe and its immediate neighbourhood. After years, Europe has to deal with a complicated international situation and a potential military threat not only in distant countries but in its immediate vicinity [1].

The Czech Republic, as an integral part of the European community, must be prepared to face these new threats and attacks both within its territory and within its commitments to the European Union. One possible target of an attack is critical infrastructure. Up to now, the attacks, in contrast to soft targets, have avoided European continent (except for Ukraine) but it does not mean that this trend will not change in the future [1].

Protecting its own critical infrastructure is one of the key tasks of each country. In the Czech Republic, this area is relatively well legislated. However, there are some areas that are not fully covered: the evaluation area [2-9], the building material testing [10-18] and the resistance of building elements [14-19].

2. Basic Principles of Protection of Critical Infrastructure Objects

The shock or explosion is a release of large amount of energy (a shock in order of MJ, an explosion in the order of GJ) and the energy is passed onto an obstacle (protective structure of critical infrastructure object) (Fig. 1) [5, 6]. Effective protection lies in a sufficient distance from the centre of the explosion and, in the event of an impact, in a sufficient reduction of impact velocity and in building materials capable of absorbing large amount of deformation energy [6]. The buildings materials that are used to protect the critical infrastructure objects must have properties that are capable of absorbing the released energy.

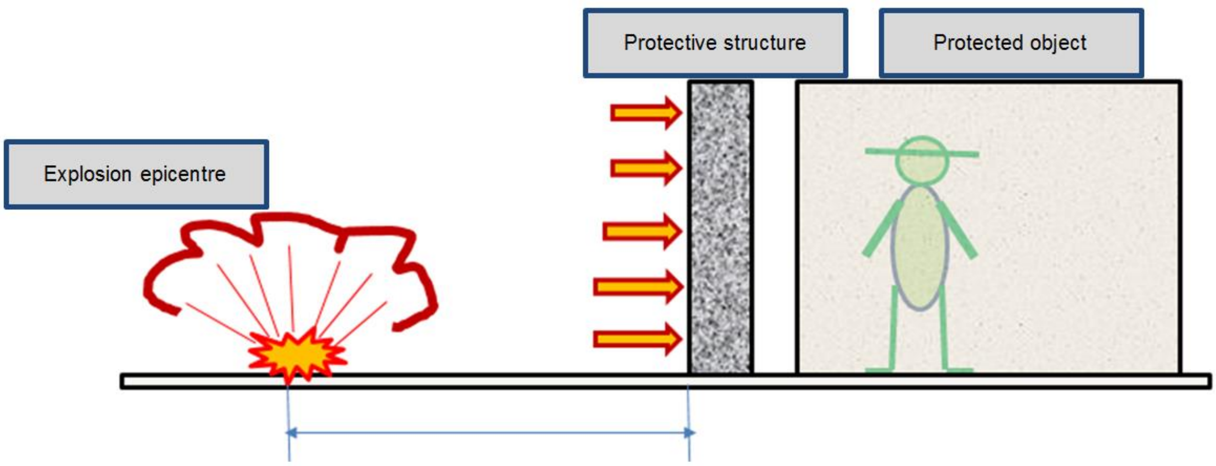


Fig. 1 Basic principles of critical infrastructure protection [6]

The building materials useful for critical infrastructure protection are, for example, wood, soil, steel, concrete, plastics or various types of composite materials. Steel is an excellent material because it can absorb large amount of

energy from the point of view of volume. Steel has the same tensile and compressive properties and it is therefore used for load-bearing structures. Its main disadvantage is the price. Concrete offers a large volume (massive construction) and excellent compressive strength and compared to steel it is cheaper.

Concrete, the building material widely used in the civil engineering, has two basic disadvantages. It has a low tensile strength and a brittle nature of the failure. In common building elements, these disadvantages are eliminated by reinforcement in the form of steel rods and nets. By positioning the reinforcement, the behaviour of the building elements change, but the concrete properties remain the same in the structure (brittleness, low tensile strength, and inhomogeneity). Different material properties can be achieved by directly reinforcing the structure of the concrete. For such reinforcement it is necessary to use reinforcing elements, the size of which corresponds to the size of the individual components in the concrete matrix which is a thread or a wire.

In conventional fibre-reinforced concrete, the fibres reduce the formation of microcracks caused by autogenous shrinkage and cracks from contraction shrinkage, and also reduce concrete permeability. Steel fibres increase toughness, impact resistance, abrasion, and generally increase the ability to withstand fracturing or breakage of concrete, thus improving the durability and usability of the concrete building elements.

The steel wires can reduce the compression strength of concrete by a small percentage, but the tensile strength of concrete increases by 50 to 100%. The increased tensile strength and ability of the fibres to act even after crack formation increase the ductility of the material under tension, bend, shear, and combined stress.

The steel wires have a modulus of elasticity higher than a concrete matrix itself, therefore they offer reinforcement and a high-quality composite (increased strength and toughness). In order to effectively utilize the material properties of the wires, it is necessary to ensure their cohesion with the concrete matrix. This cohesion is ensured by, for example, creating "hooks" at the ends of individual wires. The progressive pulling and increasing the number of thin cracks give the fibre concrete its toughness.

3. Objects of Critical Infrastructure

The critical infrastructure objects are selected public infrastructure buildings and facilities, and other elements owned or operated by different entities. The critical infrastructure entities are owners and operators of production and non-production systems that produce goods or provide services. The sensitivity and potential vulnerability of complex systems are monitored. The selection criteria are based on expert knowledge, taking into account the extent, severity and timing factor. The objects of critical infrastructure can be divided into 5 levels.

1. Compound – power plants, State Material Reserves Administration, chemical industry, public administration.
2. Object – a specific building within a compound.
3. Inside the object – a data centre in public administration building.
4. Line construction – roads, water lines, power supply lines, and data network.
5. Line construction node – major intersections, transformers, substations.

Due to the limited scope of the article, only the compound will be described. The compound usually forms one functional unit and it includes several buildings and space between them. Typically (but not always) the compound is enclosed and access for persons and vehicles is possible through one or more entrances, and in some cases, the entrance is equipped with a gateway with a surveillance system. In the paragraphs 4 to 9, there are 6 examples of critical infrastructure objects, their short description and the list of regulations they have to comply with.

4. Barrier Protection of the Compound

The barrier protection of the compound mainly consists of mechanical barriers that are distant from the object and are not a part of a secured compound. Usually these barriers are positioned outside the secured compound on the surrounding open area. The barriers visually mark the boundary of the compound, creating not only the physical but mainly its legal boundary. It can be different kinds of fences, railings or enclosures around the compound, including entrances that prevent or limit the access to the secured compound. These mechanical obstacles do not create an insurmountable boundary, but it only prolongs the time necessary to break into the secured compound. For this reason, the barrier protection must be equipped with detection and monitoring devices as required by the security level. Barrier protection elements have to be assessed according to the following regulations:

- Vehicle-ramming attack resistance – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], UFC 4-022-02 [23].
- Safe distance between the nearest communication and the barrier, barrier resistance against vehicle-ramming attacks – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], UFC 4-022-02 [23].

5. Object Setback from Barrier Protection

The distance between a secured object and the barrier protection has to be assessed according to the following regulations:

- Vehicle-ramming attack resistance – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], UFC 4-022-02 [23].
- Safe distance between the object and the nearest point of possible improvised explosion device attack –

STANAG 2280 [20], ATP-3.12.1.8 (A) [21], JRC TECHNICAL REPORTS [24].

6. Compound Entrance

The entrance control point of the compound is one of the most vulnerable points of the perimeter and its structures have to be assessed according to the following regulations:

- Vehicle-ramming attack resistance of the entrance for vehicles – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], UFC 4-022-02 [23].
- Building structure resistance of the entrance for persons – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], JRC TECHNICAL REPORTS [24], STANAG 4569 [25].

7. High-voltage Substation

The transmission network in the Czech Republic consists of two main parts, substations and high-voltage lines that connect these substations (Fig. 2). The high-voltage lines are operated at three levels: 400 kV, 220 kV and 110 kV, and there are 41 substations with total transformation power of 20 380 MVA. This transformation power is covered with 4 transformers of 400/220 kV, 46 transformers of 400/110 kV and 21 transformers of 220/110 kV [26].

Fig. 2 High-voltage substation Čebín [26]

8. High-voltage Network Mast

A high-voltage network mast is an example of a linear structure where one dimension is predominant, and in this example this is the length above the width and the height. In the category, from the critical infrastructure point of view, there belongs also high-voltage network and their masts, roads with bridges, water reservoir dams, product pipelines and data networks lines. These types of structures have to be assessed according to the following regulations:

- Vehicle-ramming attack against a barrier surrounding the high-voltage network mast – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], STANAG 4569 [25] ANSYS-AUTODYN, LS DYNA.
- Explosion close to the high-voltage network mast – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], JRC TECHNICAL REPORTS [24], STANAG 4569 [25].
- Vehicle-ramming attack against a barrier surrounding the bridge pillar – STANAG 2280 [20], ATP-3.12.1.8 (A) [22], STANAG 4569 [25].
- Explosion close to the bridge pillar – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], JRC TECHNICAL REPORTS [24], STANAG 4569 [25].
- Explosion close to a water reservoir dam – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], JRC TECHNICAL REPORTS [24], STANAG 4569 [25].
- Explosion close to a product pipeline – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], JRC TECHNICAL REPORTS [24], STANAG 4569 [25].
- Explosion close to the GSM network mast – STANAG 2280 [20], ATP-3.12.1.8 (A) [21], PAS 68 [22], JRC TECHNICAL REPORTS [24], STANAG 4569 [25].

9. Transmission Network

The 400 kV high-voltage lines in the Czech Republic, as well as the 220 kV lines and selected 110 kV lines, are

all parts of the transmission network (Fig. 3). These lines are used for a distribution of high power output from power plants and for the transmission of electricity over long distances with total length of 3510 km, of which 1146 km consists of double and multiple lines [27].

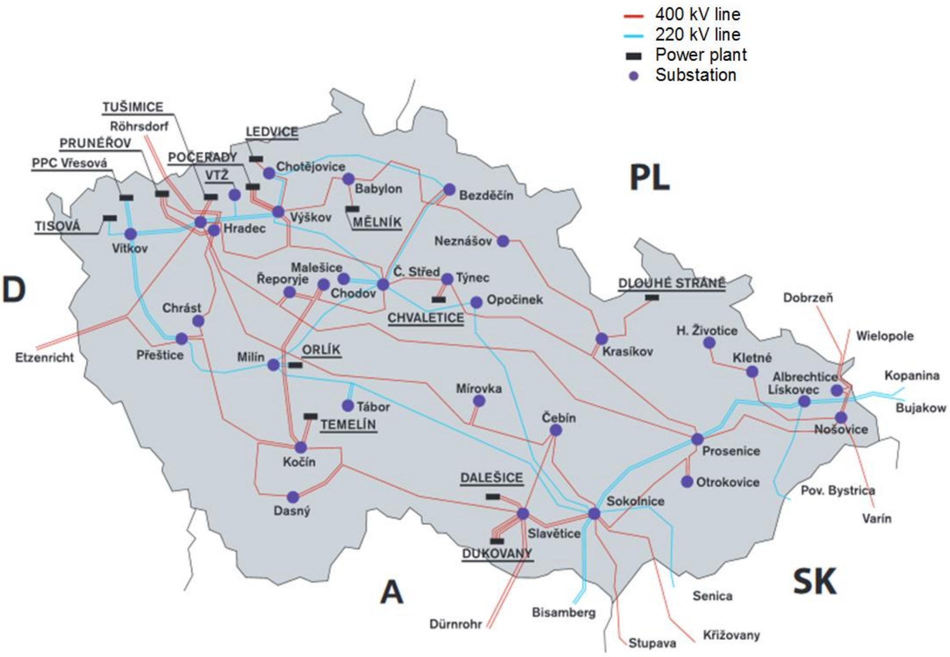


Fig. 3 The 400 kV and 220 kV power lines in the Czech Republic

10. Conclusion

The protection and enhancement of critical infrastructure has been an important topic in security research since the 1990s. At the turn of the millennium, both European and national legislation was passed in the area of critical infrastructure protection. Consequently, the main strategic documents concerning state security were amended and also security research has started to focus on the area of critical infrastructure. The urgency of this issue is constantly increasing due to the significant turbulence in the security situation in recent years, whether we are talking about the Arab Spring, the Islamic State, the conflict in Ukraine or terrorist attacks threatening citizens and institutions of the European Union.

Both European and national strategy documents list specific threats to critical infrastructure, but the precise criteria for design, verification and certification are not described. The determination of these criteria is a main goal of the research project "Research, development, testing and evaluation of critical infrastructure elements" which is currently carried out by Military Research Institute in Brno, Czech technical university in Prague and companies BOGGES, Poličské strojírny and SVS FEM.

References

1. **Hofreiter, L.; Zvaková, Z.** 2017. Theoretical Aspects of Critical Infrastructure Protection. Durability of Critical Infrastructure, Monitoring and Testing. Springer, s. 139-147.
2. **Lusková, M.; Titko, M.; Leitner, B.** Multilevel Approach to Measuring Societal Vulnerability due to Failure of Critical Land Transport Infrastructure.
3. **Luskova, M.; Leitner, B.** 2017. Critical Infrastructure Protection in Higher Education in Slovakia. In: 11th International Conference on Technology, Education and Development (INTED) Location: Valencia, SPAIN Date: MAR. 2017, s. 06-08.
4. **Figuli, L.; Štaffenova, D.** 2017. Practical Aspect of Methods Used for Blast Protection. In: Key Engineering Materials, Trans Tech Publ, 755: 139-146. ISBN 3035712360.
5. **Holub, J.; Maňas, P.** 2017. Design Tool for Static Design and Evaluation of Steel, Wood, Concrete and Masonry Members in Buildings. In: Singapore: Springer Singapore, s. 65-74. ISBN 978-981-10-3247-9.
6. **Maňas, P.** 2016. The Protection of Critical Infrastructure Objects - Technical Principles. In: Durability of Critical Infrastructure, Monitoring and Testing - Lecture Notes in Mechanical Engineering. Singapore: Springer, s. 239-248. DOI: 10.1007/978-981-10-3247-9_27. ISBN 978-981-10-3246-2.
7. **Slivkova, S.; Rehak, D.; Nesporova, V.; Dopaterova, M.** 2017. Correlation of core areas determining the resilience of critical infrastructure. Procedia engineering. Elsevier 192: 812-817. ISSN 1877-7058.
8. **Dvořák, Z.; Sventeková, E.; Řehák, D.; Čekerevac, Z.** 2017. Assessment of Critical Infrastructure Elements in

Transport, Procedia Engineering 187: 548-555. DOI: https://doi.org/10.1016/j.proeng.2017.04.413. ISSN 1877-7058. Available at: http://www.sciencedirect.com/science/article/pii/S1877705817319434

9. **Leitner, B.; Figuli, L.** 2018. Fatigue life prediction of mechanical structures under stochastic loading. In: MATEC Web of Conferences. EDP Sciences, 157, s. 02024. ISSN 2261-236X.
10. **Zezulová, E.** 2017. The Dynamic Modulus of Elasticity as an Important Parameter for Military Use of Constructions. Durability of Critical Infrastructure, Monitoring and Testing. Springer, s. 191-199.
11. **Štoller, J.; Zezulová, E.** 2017. The Basic Properties of Materials Suitable for Protective Structures and Critical Infrastructure. In: Singapore: Springer Singapore, s. 211-221. ISBN 978-981-10-3247-9.
12. **Štoller, J.; Zezulová, E.** 2017. The Application of Fibre Reinforced Concrete for Protective Shelter from Auxiliary Material, Key Engineering Materials. Trans Tech Publications 755: 374-381. DOI: 10.4028/www.scientific.net/KEM.755.374. ISSN 1662-9795. Available at: http://www.scientific.net/KEM.755.374
13. **Král, P.; Hušek, M.; Hradil, P.; Kala, J.; Maňas, P.** 2017. Optimization of the material parameters of the continuous surface cap model for concrete. In: Military Technologies (ICMT), 2017 International Conference on. IEEE, s. 298-302. ISBN 1509056661.
14. **Bílý, P.; Fládr, J.; Kohoutková, A.** 2017. Behavior of anchorage areas in the steel-concrete composite structure loaded by longitudinal shear forces, Procedia Engineering, Elsevier, 172: 104-110. ISSN 1877-7058.
15. **Šeps, K.; Fládr, J.; Broukalová, I.** 2016. Resistance of Recycled Aggregate Concrete to Freeze-thaw and Deicing Salts. Procedia Engineering. 151: 329-336. DOI: https://doi.org/10.1016/j.proeng.2016.07.367. ISSN 1877-7058. Available at: http://www.sciencedirect.com/science/article/pii/S1877705816317556
16. **Chylík, R.; Trtík, T.; Fládr, J.; Bílý, P.** 2017. Mechanical properties and durability of crumb rubber concrete. IOP Conference Series: Materials Science and Engineering. 236(1), ISSN 1757-899X. Available at: http://stacks.iop.org/1757-899X/236/i=1/a=012093
17. **Zvaková, Z.** 2016. Test procedure of the window systems reaction to a shockwave load. Production Management and Engineering Sciences. ROUTLEDGE in association with GSE Research, 577(581): 577-581. ISBN 1315673797.
18. **Kravcov, A.; Svoboda, P.; Konvalinka, A.; Cherepetskaya, E.B.; Karabutov, A.A.; Morozov, D.V.; Shibaev, I.A.** 2017. Laser-Ultrasonic Testing of the Structure and Properties of Concrete and Carbon Fiber-Reinforced Plastics. Key Engineering Materials. 722. ISSN 1662-9795.
19. **Kravcov, A.; Svoboda, P.; Konvalinka, A.; Cherepetskaya, E.B.; Sas, I.E.; Morozov, N.A.; Zatloukal, J.; Koťátková, J.** 2017. Evaluation of Crack Formation in Concrete and Basalt Specimens under Cyclic Uniaxial Load Using Acoustic Emission and Computed X-Ray Tomography. Key Engineering Materials. 722. ISSN 1662-9795.
20. Stanag 2280 Ed.2. Stanag 2280 Test Procedures and Classification of the Effects of Weapons on Structures. Ed 2. NATO: North Atlantic Treaty Organization, 2016.
21. NATO - ATP-3.12.1.8 - Test Procedures and Classification of the Effects of Weapons on Structures. Ed2. Nato: North Atlantic Treaty Organization, 2016.
22. PAS 68 Impact test specifications for vehicle security barrier systems. ED1. UK: BSI - British Standards Institution, 2010.
23. UFC 4-022-02 Selection and Application of Vehicle Barriers, with Change 1: Unified Facilities Criteria (UFC). ED2. USA: Department of Defence USA, 2010.
24. JRC Technical Report No. JRC 41337, JRC 46829, JRC 32253, JRC87202, JRC94928, JRC94812, JRC98372, JRC100438, JRC101039. Publications Office of the European Union.
25. STANAG 4569 Protection Levels for Occupants of Armoured Vehicles. Ed1. Nato: North Atlantic Treaty Organization, 2014.
26. Czech transmission and distribution network Part 2 - substation [online]. Czech Republic: http://oenergetice.cz/, 2015 [cit. 2017-12-09]. Available at: http://oenergetice.cz/technologie/ceska-prenosova-a-distribucni-soustava-2-dil-rozvodny-prenosove-soustavy/.
27. Czech transmission and distribution network Part 3 – 400 kV line [online]. Czech Republic: Oenergetice.cz, 2015 [cited 2017-12-10]. Available at: http://oenergetice.cz/elektrina/ceska-prenosova-a-distribucni-soustava-3-dil-vedeni-400-kv/.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Identification of Risks by the Transport of Drinking Water during an Emergency Event

J. Mihoková, Jakubčeková[1], M. Tomek[2]

[1]*University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, E-mail: Julia.Mihokova@fbi.uniza.sk*
[2]*Tomas Bata University in Zlín, nám. T.G.Masaryka 5555, 760 01 Zlín, Czech Republic, E-mail: Miroslav.Tomek@utb.cz*

Abstract

The paper deals with the transport of drinking water during the emergence and handling of an emergency event. Emergency supply at implementation brings with it a large number of risks and therefore it is necessary to identify these risks. We used cause-and-effect diagram method to identify possible risks. Using this method, we created a background for processing the next KARS method. This is a quantitative risk analysis that evaluates the continuity of individual risks among themselves. Using the risk comparison method, the most serious risks associated with this transport are assessed.
KEY WORDS: *causes, drinking water, effect, identification, risks, supply*

1. Introduction

The emergency supply with drinking water to the population includes processes and activities that can be dealt after effective preparation within the frame emergency supply planning without major problems. Everything depends on the character and extent of the extraordinary event.

The emergency supply of drinking water to the population includes:

- intensifying the monitoring of drinking water sources, ensuring the protection of drinking water sources and technical facilities;
- determination of the norm of consumption of drinking water for the population, management regime with drinking water;
- informing the population about the method of supplying drinking water, the place and the time of water discharge;
- organizing the distribution of drinking water (to whom, where to, when to deliver, quantity, form, who will provide water, who will arrange for it to be treated, transport, use of means of transportation, storage, manipulation, distribution) [1].

2. Identification of Risks Associated with Emergency Supply

The main source material for detecting the vulnerability of the emergency supply of water to the population is the identification of possible threats and risks. Identifying threats and risks can be the basis for building a risk reduction strategy. It is risk management to detect and minimize weak points of emergency supply.

The security of the emergency supply of water to the population can be disrupted in terms of four basic factors:

- a human factor - it is a man whose actions are deliberate or unintentional;
- Environment - is the environment of the water source, the storage and the discharge of water;
- technological facilities - technical means are used;
- Legislation regulations - laws, government orders, regulations, operating regulations [1].

The identification of risks in the emergency supply of drinking water to the population is focused on three areas of storage, transport, distribution of drinking water. There are many activities, phenomena and processes in the emergency water supply that bring with yourself a number of risks.

We know that for the term of risk is not exist specified definition, so we can characterize it as a probability of a crisis phenomenon with undesirable consequences. The mathematical expression of the risk is realized by the degree of risk, it can be calculated by the basic mathematical operation as the conjunction of the probability of occurrence of the crisis phenomenon and the possible range of consequences, the formula is as follows:

$$R = \sum_i^n P_i \times \sum_i^n D_i \,, \tag{1}$$

where R – Risk; P_i – the probability of occurrence of the crisis phenomenon; D_i – the consequence of occurrence of the crisis phenomenon [2].

To identify the risks was chosen a method of a cause and effect diagram. The impact of possible risks on emergency supply is variable. The emergence of an extraordinary supply event may arise from different situations where the supply of drinking water to the population is interrupted (Fig. 1).

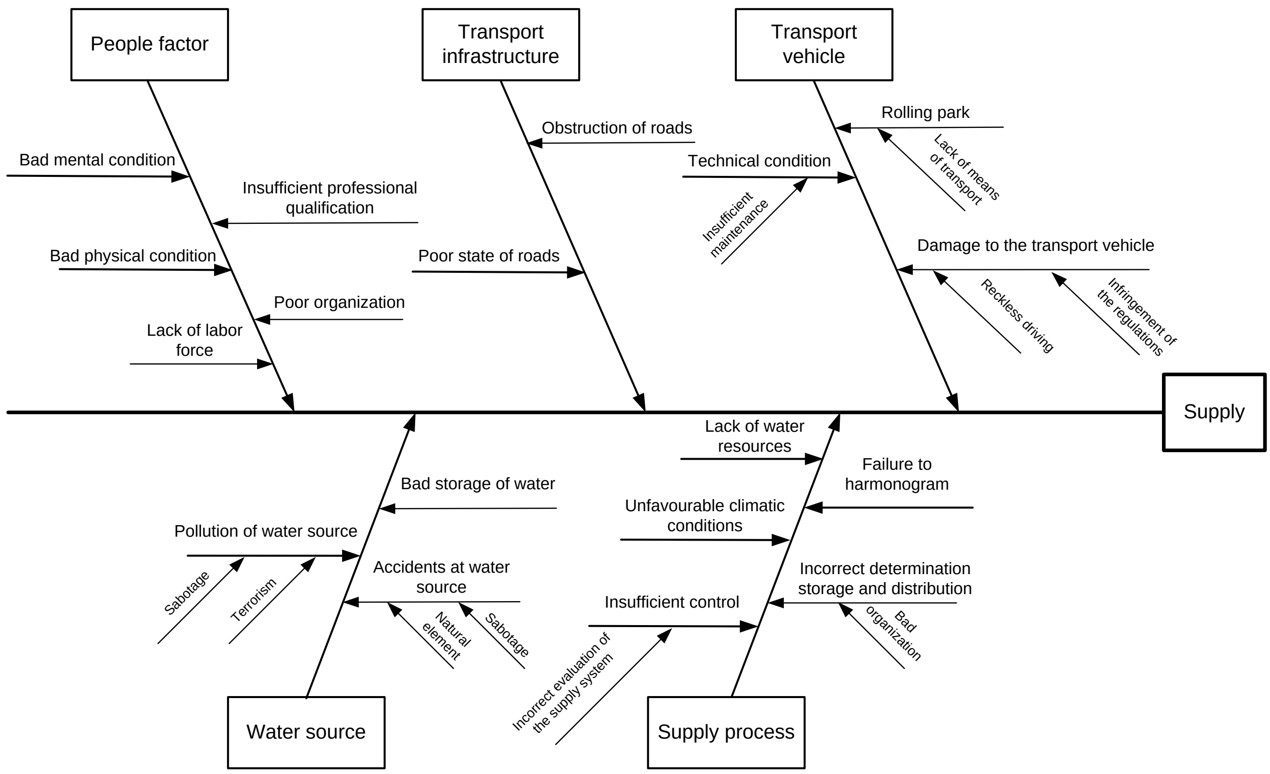


Fig. 1 Graphic representation of causes and consequences of negative impact on supplies [3]

3. Assessment of the Risks Associated with Emergency Supply

The authors of the article used for risk assessment a qualitative KARS analytical method that consisting of 8 steps [4]:

1. Processing the list of risks.
2. Compilation of Risk Correlation Table.
3. Fill of Risk Correlation Table.
4. Creating the sum of the correlation risk.
5. Calculation of the coefficient of activity and the passivity of individual risks.
6. Graphical risk assessment.
7. Calculation of axes of activity and passivity coefficient.
8. Evaluation of KARS analysis.

1. Step: The method is applied to the area of emergency drinking water supply solution during an emergency event and the individual steps were processed on the identified risks (Fig. 1), which may affect the supply of drinking water to the population:

1) Bad mental condition.
2) Insufficient professional qualification.
3) Bad physical condition.
4) Poor organization.
5) Lack of labour force.
6) Obstruction of roads.
7) Poor state of roads.
8) Rolling park (insufficient maintenance).
9) Technical condition (lack of means of transport).
10) Damage to the transport vehicle (infringement of the regulations, reckless driving).
11) Bad storage of water.
12) Pollution of water source (sabotage, terrorism).
13) Accidents at water source (natural element, sabotage).
14) Lack of water resources.
15) Failure to harmonogram.
16) Unfavourable climatic conditions.
17) Incorrect determination storage and distribution (bad organization).
18) Insufficient control (incorrect evaluation of the supply system).

2. Step: The compilation of the risk correlation table (Table 1) contains only the main causes, the main risks we have identified. The table was compiled as a matrix in which the number of rows and columns equals the number of all identified risks. Along applies to, the risk of the first line R_{1i} is at the same time the risk of the first column R_{1j} [4]:

Table 1

Table of Correlation Risk

Source of risk	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		

3. Step: We have filled out a chart of risk correlation (Table 2) [4]:

a) we know that risk cannot be self-inflicted, it means on the main diagonal matrix are all the risks zero $R_{ij} = 0$ ($i = j$);

b) To fill other cells were followed the left-to-right rows. To the position of R_{ij} ($i \neq j$) we fill in the values:

- 1 – if there is a realistic possibility that the risk of R_i may initiate the risk of R_j;
- 0 – can be set if the risk R_i does not initiate the risk of R_j.

Table 2

A filled-in table of correlation risks

Source of risk	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1
3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
5	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1
6	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0
7	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0
8	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0
9	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
16	0	0	0	0	0	1	1	0	0	1	0	1	1	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
18	0	1	0	0	1	0	0	1	1	1	1	1	1	1	1	0	1	0

4. Step: Creating a Sum of Concurrency Risk - In this step of the KARS analysis, it need to add one row to the table and the extra column (Table 3). The new column and row represent the totals of individual rows and columns. Subsequently, were obtained the risk correlation table and the individual row and column totals, which were used for calculations of activity (below „KA“) and passivity (below „KP“) coefficients [4].

Table 3

Added table of correlation risks

Source of risk	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	KA
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1	4
3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	3
5	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	7
6	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	3
7	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	3
8	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	3
9	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	3
10	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	3
11	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2
12	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2
13	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	2
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
16	0	0	0	0	0	1	1	0	0	1	0	1	1	0	0	0	0	0	5
17	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	2
18	0	1	0	0	1	0	0	1	1	1	1	1	1	1	1	0	1	0	11
KP	1	2	1	2	2	3	2	3	3	6	2	4	4	2	11	0	4	3	

5. Step: Calculation of the passivity coefficient and the activity of the individual risks - Conversion of the resultant table of risk correlation into the mathematical and in the 6 step into the graphical form. The main objective is to assess the presence of the so-called *KA* a *KP*. Where:

- *KA* marked K_{ARi} is a percentage expression of the number of follow-on risks that may be caused by the instrumentality of the risk R_i.
- *KP* marked K_{pri} is a percentage expression of the number of risks je that may be caused create a risk R_i. Percentage expression refers to the number of all the risks that can be set in the system.

For express the coefficient K_{ARi} a K_{Pri} was determined the number of combinations, when the risk of R_i may cause other risks or may be triggered. For x = the number of risks, the number of combinations is equal to x-1. Each risk is characterized by two coefficients K_{ARi} and K_{Pri}. [4] It was compiled a Table 4.

Calculation of activity and passivity coefficients was performed using the following relationships [4]:

$$K_{ARi} = \frac{\sum 1R_i}{x-1} \cdot 100, \text{ for } \sum 1 \text{ in line } i\,; \tag{2}$$

$$K_{PRi} = \frac{\sum 1R_i}{x-1} \cdot 100, \text{ pre } \sum 1 \text{ in the column } j\,. \tag{3}$$

Table 4

Table of activity and passivity

Source of risk	KA (%)	KP (%)	Source of risk	KA (%)	KP (%)
1	0	5,88	10	17,65	35,29
2	23,53	11,76	11	11,76	11,76
3	5,88	5,88	12	11,76	23,53
4	17,65	11,76	13	11,76	23,53
5	41,18	11,76	14	0	11,76
6	17,65	17,65	15	5,88	64,71
7	17,65	11,76	16	29,41	0
8	17,65	17,65	17	11,76	23,53
9	17,65	17,65	18	64,71	17,65

6. Step: Graphical Risk Assessment - to more clearly process the results of Step 5 was used a graphical view and evaluation by the means the Correlation Graph - Dependency Graph (Fig. 2). On the x axis were applied the K_{ARi} values and on the y axis the K_{Pri} values for the individual risks [4].

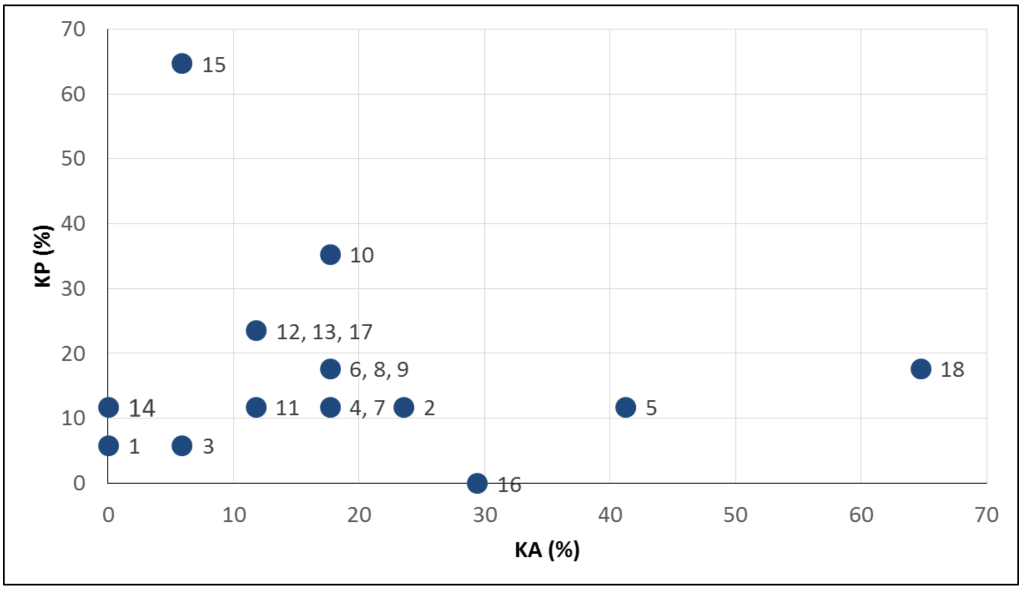


Fig. 2 Correlation graph

7. Step: Calculation of coefficient axes of activity and passivity - the objective of this step was to determine the significance of the individual risks according to their compatibility with the other risks in the process. Determining the significance of the risks was achieved by dividing the graph into four basic areas, namely be the means the O_1 and O_2 axes. These areas determine how significant the risk is in them. The O_1 axis was constructed as a perpendicular to the *x* axis and the O_2 axis as perpendicular to the *y* axis. The value at which O_1 axis resp. O_2 intersect axis *x* resp. *y*, was calculated according to the established formulas. Before calculating, it was necessary to determine what part of the risks we wanted to cover by dividing the quadrants.

Formula for calculation O_1 and O_2 [4]:

$$O_1 = K_{A_{max}} - \frac{K_{A_{max}} - K_{A_{min}}}{100} \cdot 80, \text{ for cover 80\% all risks}; \tag{4}$$

$$O_2 = K_{P_{max}} - \frac{K_{P_{max}} - K_{P_{min}}}{100} \cdot 80, \text{ for cover 80\% all risks}. \tag{5}$$

In our case, the size of the axes will be (Fig. 3):

From the relationship (4): $O_1 = 64{,}71 - \frac{64{,}71 - 0}{100} \cdot 80 = 12{,}942$.

From the relationship (5): $O_2 = 64{,}71 - \frac{64{,}71 - 0}{100} \cdot 80 = 12{,}942$.

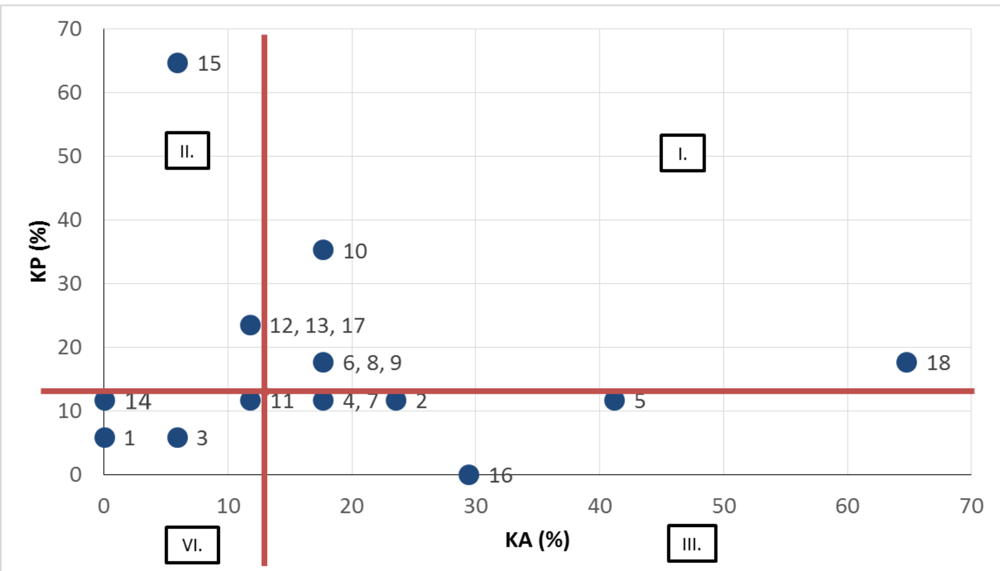


Fig. 3 Split-in the graph into quadrants

8. Step: Evaluation of the method. The resulting areas (quadrants) are [4]:

I. area (*primary and secondary hazards risks*):

6 - Obstruction of roads.
8 - Rolling park (insufficient maintenance).
9 - Technical condition (lack of means of transport).
10 - Damage to the transport vehicle (infringement of the regulations, reckless driving).
18 - Insufficient control (incorrect evaluation of the supply system).

II. area (*secondary hazards risks*):

12 - Pollution of water source (sabotage, terrorism).
13 - Accidents at water source (natural element, sabotage).
15 - Failure to harmonogram.
17 - Incorrect determination storage and distribution (bad organization).

III. area (*primary hazards risks*):

2 - Insufficient professional qualification.
4 - Poor organization.
5 - Lack of labour force.
7 - Poor state of roads.
16 - Unfavourable climatic conditions.

IV. area (*relatively hazards risks*):

1 - Bad mental condition.
3 - Bad physical condition.
11 - Bad storage of water.
14 - Lack of water resources.

Based on the risk analysis using the KARS method, we have identified the risks that need to be given the most attention. Planning should take into account all appropriate means to minimize the potential inception threat that we have identified.

4. Conclusions

An essential step for managing the emergency drinking water supply solution is primarily the assessment of the inception of an extraordinary event. The content of the review could be:

- observation of the cause of decommissioning of the public water main;
- the characteristics of the situation that contains the information on the public water supply that is supplies with the drinking water and the number of wells that meet the hygienic checks;
- analysis of damages incurred in public water supply and estimation of decommissioning of the public water main;
- To determine the exact number of persons to be supplied with drinking water [1].

Emergency drinking water supplies brings a number of threats and risks that could disrupt the functioning of the supply system. Therefore, it is necessary to identify all possible causes and consequences of the occurrence of an extraordinary event. On the basis of the assessment, to create a range of the most serious risks that could affect the efficiency of emergency drinking water supply.

Acknowledgement

This work was supported by Project VEGA No.1/0240/15 Process model of safety and protection of critical infrastructure in the transport sector.

References

1. **Tomek, M.; Jakubčeková, J.; Benčíková, E.** 2011. Núdzové zásobovanie obyvateľstva pitnou vodou. Žilina: EDIS, 189 s. ISBN 978-80-554-0521-6. (in Slovak)
2. **Šimák, L.** 2006. Manažment rizík. Žilina: FŠI ŽU, 116 s. (in Slovak)
3. **Mihoková Jakubčeková, J.; Benčíková, E.** 2016. Securing the transportation in emergency situation during critical infrastructure failure. In: Transport means 2016: proceedings of the 20th international scientific conference: October 5-7, 2016 Juodkrante, Lithuania. ISSN 1822-296X. Kaunas: Kaunas University of Technology, 2016. s. 279-286.
4. **Jelšovská, K.**; **Peterková, A.** 2013. Řešení krizových situací – metody a jejich aplikace. Slezská univerzita v Opavě [online cit.: 2018-04-11]. Available from: http://projects.math.slu.cz/ AM/activ/ soubory/opory/ ResKrizi.pdf

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Determine the Position and Attitude of UAV in Air Navigation Based on GNSS Data

D. Wierzbicki

Faculty of Geodesy and Civil Engineering, Military University of Technology, W. Urbanowicza 2 Street, 00-908 Warszawa, Poland. E-mail: damian.wierzbicki@wat.edu.pl.

Abstract

In recent years unnamed aircrafts gaining vivid data for the purposes of photogrammetry and the remote sensing are equipped with satellite receivers. Single frequency GPS receivers which the accuracy of appointing the position is taking out a few meters are mainly installed on the platform of an unmanned aircraft. Possibilities of applying data from the technical infrastructure of the receiver GPS for determining navigational parameters of the unmanned aircraft are presented in this article. As part of research works a position and the speed of motion of the unmanned aircraft, as well as values of angles of the Heading, Pitch and Roll rotation were appointed. Moreover, for every value of the Heading, Pitch and Roll angle, change over time was also appointed in the form of the rate parameter.
Key words: *GPS, photogrammetry, UAV, Heading, Pitch, Roll*

1. Introduction

Implementation of the inertial navigation system and GNSS satellite navigation on UAVs has become almost a standard. These systems enable fully autonomous flights and registration of approximate elements of the external orientation of each image taken during the flight. Basic navigational apparatus placed in unmanned aircraft platform is equipped with the satellite receiver GPS. Single frequency GPS receiver is usually placed on the board the platform of unmanned aircraft that allows to specify the position of the device in three-dimensional space. The assumed accuracy of determine the position of the unmanned aircraft for single frequency GPS receiver is approximately 10 m [1]. Set coordinates of the unmanned aircraft ae related by the GNSS receiver to the geocentric XYZ or the geodetic BLh arrangement or the local ENU frame [2]. In addition, it should be added that the standard intervals of the registration and the record of set coordinates of the unmanned aircraft equals between 0.25 s and 2 s. Set coordinates of the unmanned aircraft allows to determine the distance traveled by the platform for the duration of the flight. The GPS receiver built in into the navigational system of the unmanned aircraft also allows for determining the parameters as navigational as the airspeed or angles of the HPR turnover (Heading, Pitch, Roll). Components of the vector speed are determined along each coordinate axis ENU and determine the relative rate of movement of platform. The angles of HPR turnover are related to the local system of ENU coordinates and determined on the basis of the values of the angles with HPR epoch measurement „t" and„t+1" [3].

Due to the intensive development of unmanned aerial vehicles (UAVs) techniques, they are widely used in the field of photogrammetry. The image data obtained from the Unmanned Aerial Vehicles allows us to obtain a number of basic photogrammetry products applicable in many areas related to spatial information. In addition, unmanned aerial vehicles, due to their size, are a perfect photogrammetry tool for performing air strikes over areas inaccessible eg. to mountain areas. Most of these platforms are equipped with gyroscopic stabilization and allow for autonomous flighting. In addition, the costs of such a system and operating costs are much smaller than traditional methods of obtaining aerial photogrammetric data. As a result, the acquired image data is burdened with several-meter positioning errors, which in turn translates into the final accuracy of a photogrammetric product. Today, few UAV platforms do not have a GNSS/ INS navigation system. Even these cheap models are equipped with simple systems that allow a stable flight. Using the navigation system, UAV performs a flight on a previously planned route, acquiring images from a specified height and with a specified side and forward overlap in accordance with the photogrammetric flight plan. The photogrammetric flight plan and the selection of the appropriate measuring equipment (in this case, the UAV platform, camera and navigation systems) should be made taking into account factors characterizing the type and terrain. It should also take into consideration the intended use of the photogrammetry product and the expected accuracy of the study. Planning the photogrammetric flight is the first stage of the work in which the appropriate route and flight parameters should be selected. Using the automatic and semi-automatic platforms, it is possible to plan the photogrammetric flight using special software depending on the defined parameter values.

Exploiting the technical infrastructure of the GPS receiver for determining navigational parameters of the platform of the unmanned aircraft is the aim of the study. In frames of the article parameters were described: coordinate values, flight speed, the angles of rotation of the HPR, rate angles of rotation of the HPR for the unmanned aircraft. Measuring data for research experiment comes from the photogrammetric coating data obtained from the unmanned Trimble UX-5 device in 2016 in the mountain area (southern Poland). The article was divided into three sections and references were added at the end of this paper.

2. The Research Methods and Experiment. Results and Discussion

Single frequency GPS receiver determines the position of the unmanned aircraft with using the SPP method for code C/A observation.

The basic observation equation for SPP method as fallow [4]:

$$l = d + c\times(dtr - dts) + Trop + \mathrm{Re}\,l + Ion + bias + M_l, \tag{1}$$

where l - code C/A measurement on the L1 frequency; d - geometric distance between GPS satellites and receiver; $d=\sqrt{(X_r-X_s)^2+(Y_r-Y_s)^2+(Z_r-Z_s)^2}$; (X_r,Y_r,Z_r) - position of the plane in the geocentric frame; (X_s,Y_s,Z_s) -position of the satellite GPS on the orbit; c - speed of light; dtr - receiver clock bias for observation GPS; dts - clock bias of the satellite GPS; $Trop$ - tropospheric delay for GPS observation; Ion - ionospheric delay for observation GPS; Rel - relativist effects for observation GPS; $bias$ - summary expression for hardware delays in the system GPS; M_l - the effect of the multipath effect and the measuring noise.

In the Eq. (1) the position of the unmanned aircraft is expressed with geocentric XYZ coordinates in the global WGS-84 arrangement. In the satellite technique GPS coordinates of the unmanned aircraft are determine on the basis of data from the navigational telegram and measurements pseudo distances. Determination of coordinates of the unmanned aircraft in the Eq. (1) takes place usually with the use of the method of Kalman filtering [5].

Ultimately coordinates of the unmanned aircraft can be expressed:

– in geodetic system BLh (B - geodetic width, L - geodetic length, h - ellipsoid height), as below [5]:

$$\begin{cases} B = a\ tan\left(\dfrac{Z/\rho}{1-e^2}\right) \\ L = a\ tan\left(\dfrac{Y}{X}\right) \\ h = \dfrac{\rho}{cos\ B} - R \end{cases}, \tag{2}$$

where a,b - semi-major and semi-minor axes of the WGS-84 ellipsoid; a = 6378137.0 m; b = 6356752. 314245 m; e - eccentricity; $e=\sqrt{\dfrac{a^2-b^2}{a^2}}$; e^2 = 0.006694380023; R - radius of the curvature of the prime vertical; $R=\dfrac{a}{\sqrt{1-e^2\cdot\sin^2 B}}$; $\rho=\sqrt{X^2+Y^2}$; (X,Y,Z) - geocentric coordinates of UAV; (B,L,h) - geodetic coordinates of UAV;

– or in local system ENU (East-North-Up), as below [7]:

$$\begin{cases} \Delta E = -sin\,L\cdot\Delta X + cos\,L\cdot\Delta Y + 0\cdot\Delta Z \\ \Delta N = -cos\,L\cdot sin\,B\cdot\Delta X - sin\,L\cdot sin\,B\cdot\Delta Y + cos\,B\cdot\Delta Z \\ \Delta U = cos\,L\cdot cos\,B\cdot\Delta X + sin\,L\cdot cos\,B\cdot\Delta Y + sin\,B\cdot\Delta Z \end{cases}, \tag{3}$$

where (E,N,U) - the co-ordinate antennas of receiver GPS in navigational system *ENU*.

The Fig. 1 presents the trajectory of the flight of an unmanned aircraft related to geodetic system BLh. The photogrammetric flight was conducted in 2016 in the mountain area (southern Poland) with usage of Trimble UX-5 platform. The area covered mountainous and partially wooded terrains. The aviation mission was carried out in difficult weather conditions and lighting. The obtained digital images were written down in the format of JPEG lossy compression with radiometric resolution 8 bit/channel [7].

The experiment was conducted for 22 rows of images, taken by Trimble UX-5 measuring device in test area. The photogrammetric flight was conducted in area about 1 km2, in addition the change of the geodetic B width took out between49.38769^0 and 49.39729^0, and however the change of the geodetic length L was between 21.02019^0 and 21.03213^0. The change of the ellipsoid height for the conducted flight was between 781.14 m and 806.26m and equals 25.12m.

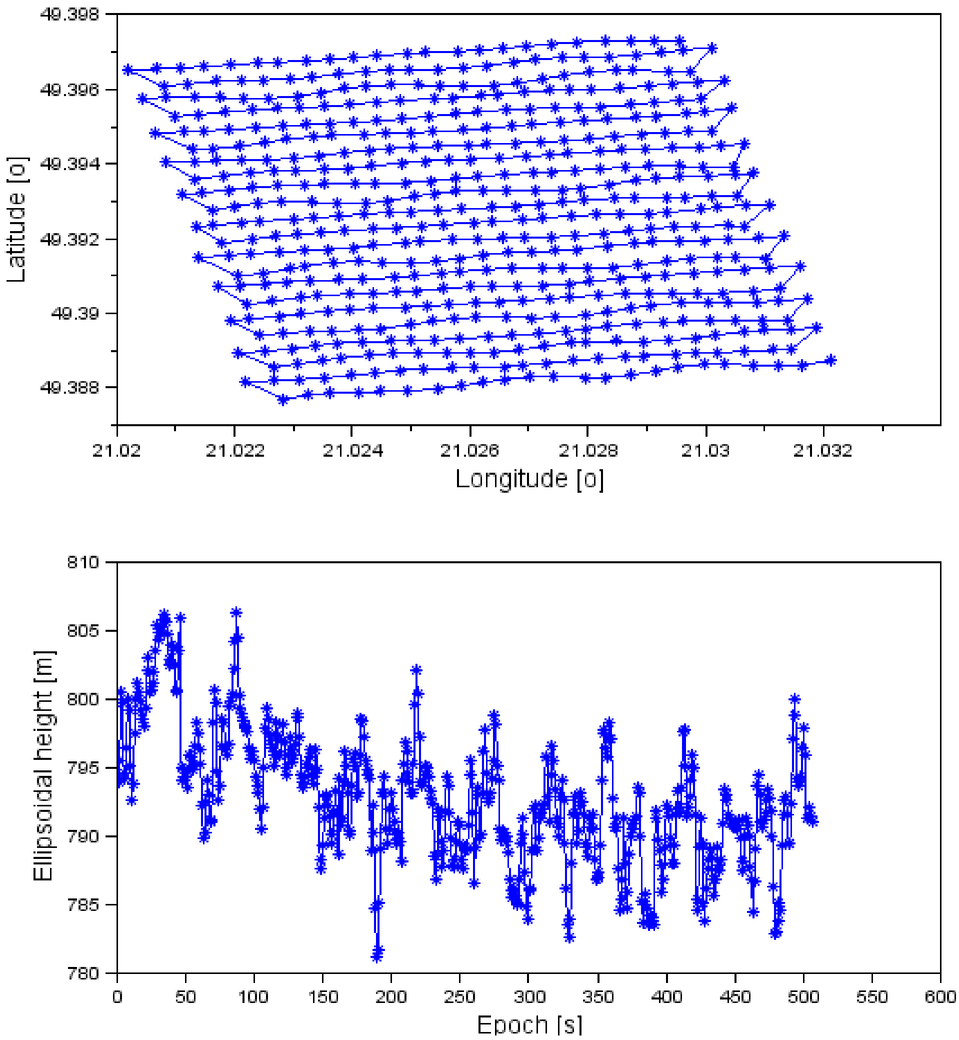
The relative speed of the flight of the unmanned aircraft was determined in the local ENU model and is expressing the change of ENU coordinates in the determined interval of the time, according to equations [8]:

$$\begin{cases} V_E = \dfrac{\Delta E}{\Delta t} \\ V_N = \dfrac{\Delta N}{\Delta t}, \\ V_U = \dfrac{\Delta U}{\Delta t} \end{cases} \tag{4}$$

where V_E - velocity along to East (E) axis; V_N - velocity along to North (N) axis; V_U - velocity along to Up (U) axis, Δt - time interval.

The relative speed is determined for the unmanned aircraft, during shooting, independently for each series.

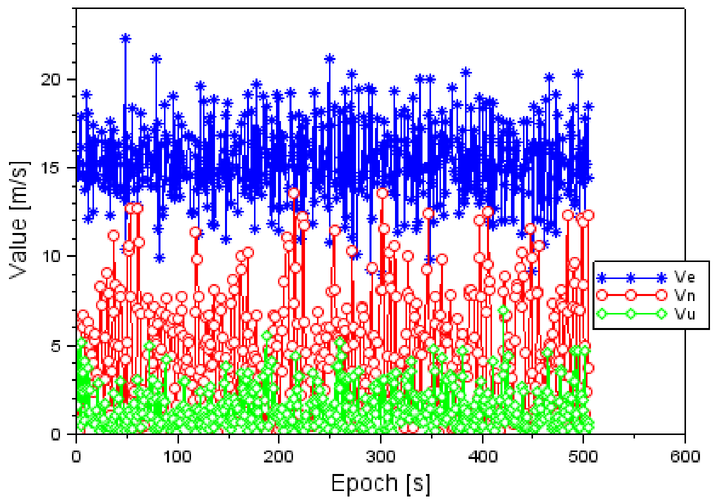
The value of the airspeed of the unmanned aircraft is expressed in individual 1 m/s.



Source: Author's own work, developed on the basis of Scilab software

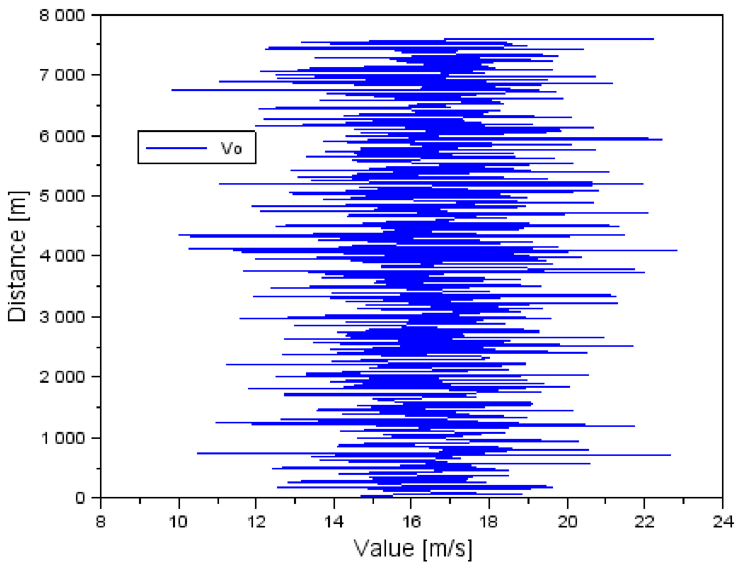
Fig. 1 The UAV coordinates in geodetic frame BLh

The Fig. 2 presents relative speed of the flight of the unmanned aircraft related to the local ENU system. The value of the speed along the E axis fluctuates 8.97 m/s to 22.28 m/s, in addition the average speed is 15.31 m/s. One should be underline that the dispersion of results for the speed is biggest of results presented on Fig. 2. The speed parameter along the N axis receives the results between 0.11 m/s and +13.56 m/s. The average value of V_N speed equals 4.88m/s., whereas the median for this parameter equals 4.60 m/s. The value of speed for V_U parameter equals between 0.01 m/s and 6.98 m/s. Moreover the average value of V_U parameter equals 1.49 m/s, whereas the median 1.19 m/s accordingly. Additionally the parameter has the smallest scattering of results in comparing to the V_E and V_N speeds.



Source: Author's own work, developed on the basis of Scilab software

Fig. 2 The UAV velocity for each axis



Source: Author's own work, developed on the basis of Scilab software

Fig. 3 The total velocity of UAV in relation to length distance

By identifying the airspeeds of the unmanned aircraft along each axis of the local ENU model, determination of the total airspeed in relation to the distance covered route through the platform is possible, as below [8, 9]:

$$\begin{cases} V_0 = \sqrt{V_E^2 + V_N^2 + V_U^2} \\ s = \sqrt{\Delta E^2 + \Delta N^2 + \Delta U^2} \end{cases}, \tag{5}$$

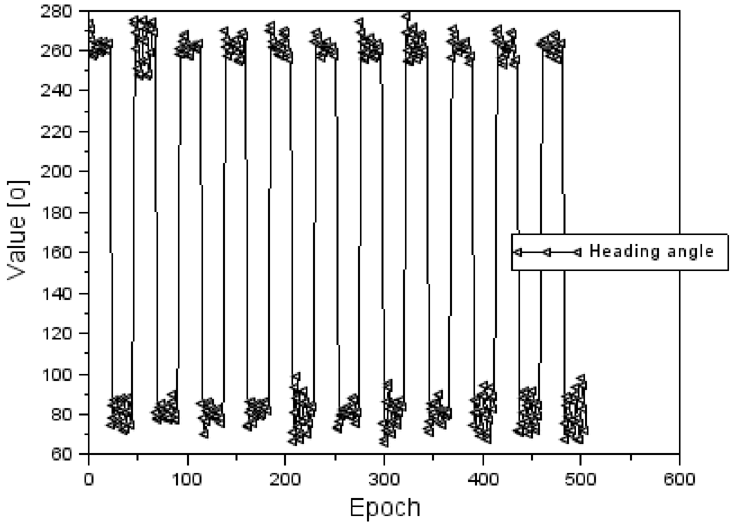
where V_0 - total velocity of UAV; s - length distance in flight mission.

The Fig. 3 presents graph of the total speed of the unmanned aircraft in the function distances travelled. The average value of the speeds of an unmanned aircraft equals 16.41 m/s with standard deviation of 2.49 m/s. It should be added that scattering of results for the parameter of the total movement speed of UX-5 platform equals between 9.79 m/s and 22.85 m/s. In addition, median parameter for total speed parameter equals 16.29 m/s. It is worthwhile to note that V_0 speed parameter is less than 20 m/s for 92% of obtained results and 29% of results are less than 15 m/s accordingly. Moreover, total distance travelled by unmanned aircraft equals around 7.6 km.

The sense of direction of the unmanned aircraft in the airspace is determined by angles of the HPR rotation. Values of HPR angles are determined in local ENU mode based on GPS solution, as below [10]:

$$\begin{cases} \psi = arctg\left(\dfrac{\Delta E}{\Delta N}\right) \\ \theta = arctg\left(\dfrac{\Delta U}{\sqrt{\Delta N^2 + \Delta E^2}}\right), \\ \phi = arctg\left(\dfrac{\Delta U}{\Delta E}\right) \end{cases} \tag{6}$$

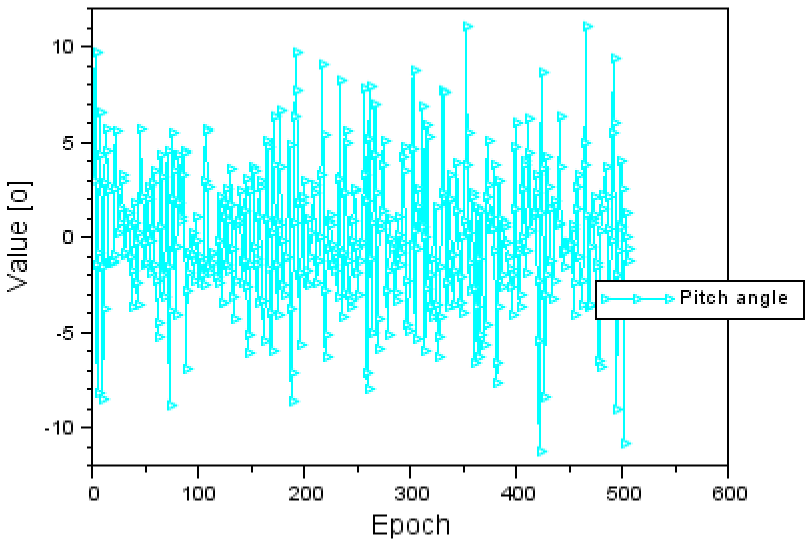
where ψ - Heading angle; θ - Pitch angle; ϕ - Roll angle.



Source: Author's own work, developed on the basis of Scilab software

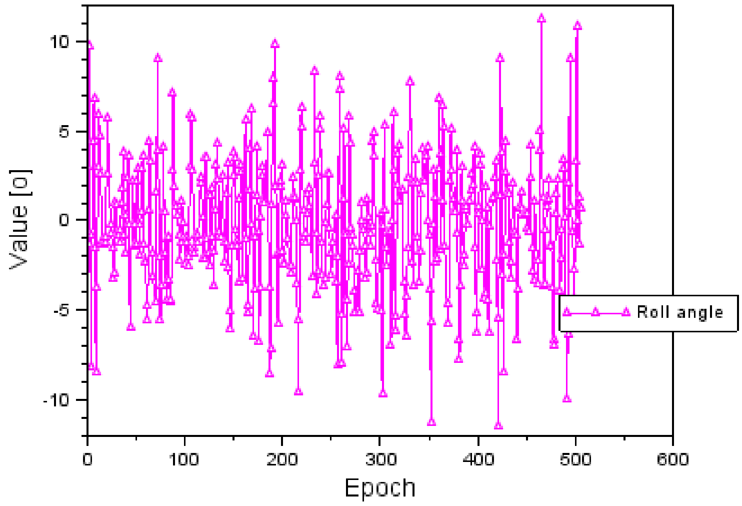
Fig. 4 The results of Heading angle based on GPS solution

The Figs. 4, 5 and 6 present values of Heading, Pitch and Roll angles for each measuring epoch. The spread of results for Heading angle equals between 65.53^0 and 277.31^0. One should be added that the Heading angle is changing its values in the time due to changes in the course of the flight from east to west or vice versa. Heading angle equals between 65^0 and 100^0 for rows of images with even numbers between 2 and 22. Moreover Heading angle changes its values from 245^0 to almost 280^0 for rows of images with odd numbers between 1 and 21.



Source: Author's own work, developed on the basis of Scilab software

Fig. 5 The results of Pitch angle based on GPS solution



Source: Author's own work, developed on the basis of Scilab software

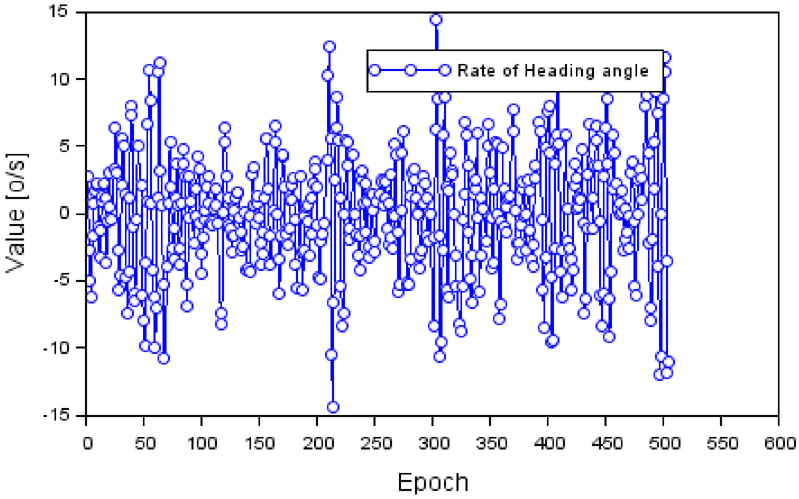
Fig. 6 The results of Roll angle based on GPS solution

Average value of Pitch Angle equals 0.06^0 and average value of Roll angle equals -0.20^0 accordingly. The dispersion of obtained Pitch angle value equals between -11.26^0 and 11.15^0 and between -11.56^0 and 11.19^0 for Roll angle accordingly. Median value for Pitch angle equals -0.22^0 and -0.31^0 for Roll angle accordingly. It should be added that values of Pitch and Roll angles in between -5^0 and +5^0 are for 83% of obtained results.

The rate of parameter determines the change of the value of HPR angles from the age to the age in the time function [11] and can be determined based on the relation:

$$\begin{cases} d\psi = \dfrac{\psi_{t+1} - \psi_t}{\Delta t} \\ d\theta = \dfrac{\theta_{t+1} - \theta_t}{\Delta t} \\ d\phi = \dfrac{\phi_{t+1} - \phi_t}{\Delta t} \end{cases}, \tag{7}$$

where $d\psi$ - rate of Heading angle; $d\theta$ - rate of Pitch angle; $d\phi$ - rate of Roll angle; $t+1$ - index of current epoch; t - index of previous epoch.

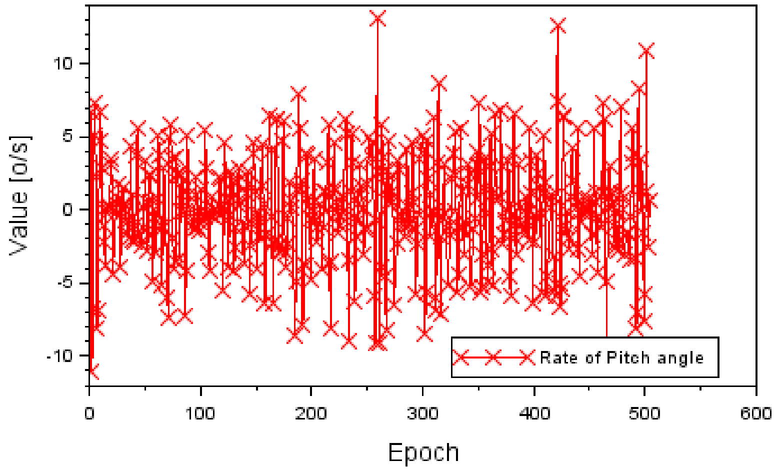


Source: Author's own work, developed on the basis of Scilab software

Fig. 7 The rate values of Heading angle

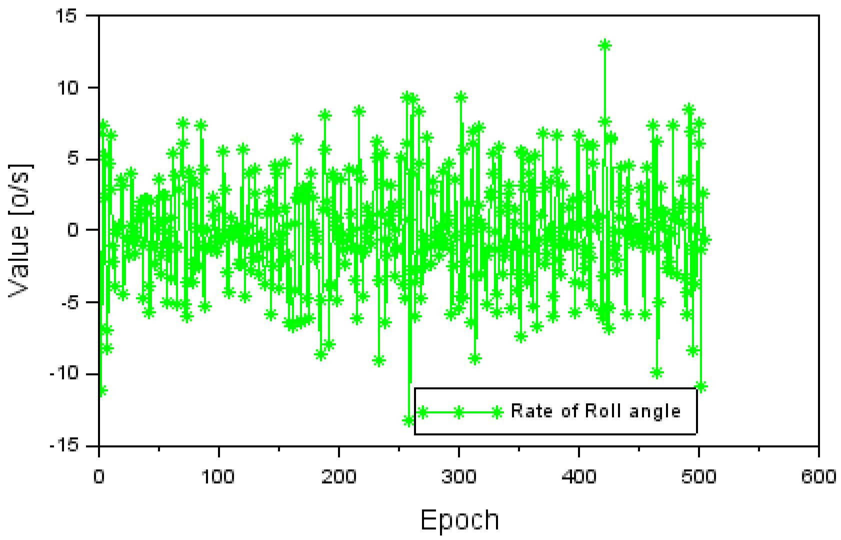
Results of rate parameter for rotation of HPR angle in the function of epoch measurement number are presented in Figs. 7, 8 and 9. Average rate value foe Heading angle equals -0.03^0/s, in addition the dispersion of obtained results equals -14.41^0/s and 14.43^0/s. Moreover, standard deviation for Heading angle rate equals 4.51^0/s, and median equals 0.11^0/s. It is worth to add that 72% of results for Heading angle rate parameter are between -5^0/s and 5^0/s. Average value

of rate for Pitch angle equals -0.02^{0}/s, in addition the dispersion of obtained results equals between -11.12^{0}/s and 13.16^{0}/s. Moreover, standard deviation for Pitch angle rate equals 3.72^{0}/s, and median equals -0.04^{0}/s. Average value of rate for Roll angle equals -0.01^{0}/s in addition the dispersion of obtained results equals between -13.27^{0}/s and 12.97^{0}/s. Standard deviation for Roll angle rate equals 3.78^{0}/s, and median equals -0.08^{0}/s.



Source: Author's own work, developed on the basis of Scilab software

Fig. 8. The rate values of Pitch angle



Source: Author's own work, developed on the basis of Scilab software

Fig. 9 The rate values of Roll angle

3. Conclusions

The practical application of the satellite GNSS technique in the technology of unmanned aircraft, particularly in the aspect of the determination of position and orientation were presented in this article. In this paper, results of determination of coordinates the speed, angles of the rotation and the rate of angles of the rotation for the unmanned aircraft were presented. Coordinates of the unmanned aircraft were determined in the geodetic BLh arrangement on the basis of the method of the positioning of absolute satellite SPP. The relative speed parameters of unmanned aircraft were determined in local ENU mode and the total speed of motion of the UX-5 platform was determined. The sense of direction in the space of the UX-5 platform was determined with Heading, Pitch and Roll rotation angles in the local ENU arrangement. Moreover, change over time in the form of rate was determined for each value of HPR angle. The input for research experiment was registered through Trimble UX-5 measuring devices during the photogrammetric flight conducted in 2016. in the mountain area (southern Poland).

Acknowledgements

Many thanks to Prof. Michał Kędzierski for his great help in acquiring data.

References

1. **Eling, C.; Wieland, M.; Hess, C.; Klingbeil, L.; Kuhlmann, H.** 2015. Development and evaluation of a UAV based mapping system for remote sensing and surveying applications, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-1/W4, 2015, International Conference on Unmanned Aerial Vehicles in Geomatics, 30 Aug–02 Sep 2015, Toronto, Canada.
2. **Wierzbicki D**. 2017. The prediction of position and orientation parameters of UAV for video imaging The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, International Conference on Unmanned Aerial Vehicles in Geomatics, 4–7 September 2017, Bonn, Germany, doi.org/10.5194/isprs-archives-XLII-2-W6-407-2017, 2017
3. **Wierzbicki, D.; Krasuski, K.** 2015. Estimation of rotation angles based on GPS data from a UX5 Platform, Measurement Automation Monitoring 61(11): 516-520.
4. **Schaer, S.** 1999. Mapping and predicting the Earth's ionosphere using global positioning system, Ph. D. Thesis, Neunundfünfzigster Band volume 59, ISBN: 3-908440-01-7, Astronomy Institute, University Bern, Switzerland.
5. **Navidi, N.; Landry, R.J.** 2015. A new survey in self-tuning integrated low-cost GPS/INS vehicle navigation system in harsh environment, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-1/W4, 2015 International Conference on Unmanned Aerial Vehicles in Geomatics, 30 Aug–02 Sep 2015, Toronto, Canada.
6. **Sanz Subirana, J.; Juan Zornoza, J.M.; Hernández-Pajares, M.** 2013. GNSS Data Processing, Volume I: Fundamentals and Algorithms, ESA Communications, ESTEC, Noordwijk, Netherlands, ISBN: 978-92-9221-886-7.
7. **Kedzierski, M.; Fryśkowska, A.; Wierzbicki, D.; Nerć, P.** 2016. Chosen aspects of the production of the basic map using UAV imagery Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLI-B1, doi:10.5194/isprs-archives-XLI-B1-873-2016, 2016, pp. 873-877.
8. **Ćwiklak, J.; Krasuski, K.; Jafernik, H.** 2017. Designation the velocity of Cessna 172 aircraft based on GPS data in flight test, 23rd International Conference Engineering Mechanics 2017, ISBN 978-80-214-5497-2, ISSN 1805-8248, pp. 262-265, Svratka, Czech Republic, 15 – 18 May 2017.
9. **Krasuski, K.; Ćwiklak, J.** 2017. Determination of a trajectory of a moving car vehicle based on the GNSS satellite technology, References: 17th International Multidisciplinary Scientific GeoConference SGEM 2017, www.sgem.org, SGEM2017 Conference Proceedings, ISBN 978-619-7408-02-7 / ISSN 1314-2704, 29 June - 5 July, 2017, 17(22): 219-228 pp, DOI: 10.5593/sgem2017/22/S09.027.
10. **Alkan, R.M.; Baykal, O**. 2001. Survey Boat Attitude Determination with GPS/IMU Systems, The Journal of Navigation 54: 135-144.
11. **Kwela, J.** 2010. Mechanika klasyczna i relatywistyczna, Skrypt z fizyki, Gdańsk, Wydawnictwo Uniwersytetu Gdańskiego, ISBN: 978-83-7326-703-9. (in Polish)

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Determining the Position Using Neural Network

M.Polasek[1], V. Pucek[2], J. Nemecek[3], R. Bloudicek[4]

[1]*University of Defence in Brno, Kounicova 65,66210, Brno, the Czech Republic, E-mail: martin.polasek@unob.cz*
[2] *University of Defence in Brno, Kounicova 65,66210, Brno, the Czech Republic, E-mail: vojtech.pucek@unob.cz*
[3]*University of Defence in Brno, Kounicova 65,66210, Brno, the Czech Republic, E-mail: jiri.nemecek@unob.cz*
[4]*University of Defence in Brno, Kounicova 65,66210, Brno, the Czech Republic, E-mail: radim.bloudicek@unob.cz*

Abstract

This paper deals with passive measurement of an object (camera) position based on the position of optical beacon. The optical beacon consists of light sources that are arranged in a specific geometric pattern. Due to the change of the camera position against the beacon, there is also a change in the mutual position of the light sources in the image captured by the camera. A neural network that can determine mutual position of the camera and the beacon, can also evaluate the light sources mutual positions. A description of the artificial neural network design together with experimental measurement results are presented in this paper. In addition, positional errors for the neural networks with different neurons in a hidden layer are evaluated.
KEY WORDS: *computer simulation, curve fitting, image processing, indoor navigation, neural networks*

1. Introduction

A satellite navigation (GPS, GLONASS, Galileo, etc.) often combined with inertial navigation system (INS) [1] is currently the most commonly used navigation of mobile devices, such as autonomous vehicles, drones or aircraft. However, this mode of the navigation is conditioned by the reception of satellite signals, which may not always be available and may be disturbed. A typical example is the navigation inside buildings, in a forest or under water [2]. For these situations, it is better to use an optical navigation. One option is to use a stereo vision [3,4] or the combination of one camera and another sensor in the form of the sonar or laser rangefinder [5,6]. This article describes the principle and practical verification of determining the position of the camera relative to an optical beacon. A similar principle is described in [7] where barcodes are used as the beacon. The barcode solution allows positioning only in 2D whereas the method presented in this article enables us to determine the relative position in the 3D space. Our method is therefore suitable for drones, for example.

The light beacon consists of a central wall and two side walls that are connected through hinges. Thanks to this, the side walls can be adjusted at different angles to the central wall. For experimental verification of the method, the sidewall angle was set to $\beta = 45°$. The optical beacon walls were printed on a 3D printer. There are nine white light emitting diodes (LEDs) (diodes S_1 ... S_9) on the walls, which create a characteristic pattern, see Fig. 1.

2. Description of the Method

The proposed method is based on the fact that the position of the diodes in the picture unambiguously depends on the relative position of the camera and the beacon. During an experimental verification, the camera's optical axis was oriented on the S_1 diode. The artificial neural network (ANN) described in [8] is used to calculate the camera position relative to the beacon. The input vector of the neural network consists of 16 elements. The first eight represents the pixel distances of the diodes S_2 to S_9 relative to the diode S_1 obtained from the image. These distances are then normalized so that they do not exceed value 1. The other eight elements represent the angles between horizontal plane and the line connecting S_1 and other diodes. These angles are also normalized to $\langle -1; 1\rangle$. The output vector contains three elements, the range R, horizontal angle ω, and vertical angle ψ, which define the relative position of the camera and the beacon, see Fig. 2.

The Mintron OS-45D CCD B/W camera with an analog output and lens with a focal length of 25 mm was used to experimentally verify the method. The analog signal was then digitized to a resolution of 640 × 480 pixels. To obtain the training data for ANN, a special function in Matlab was created. This function generated, as its output, pixel coordinates of the diodes from the captured picture based on the mutual position of the camera (optical axis) and the beacon. The ranges of the set parameters are shown in Table 1. Altogether 15336 training samples were created to train the ANN with the regression. The topology with one hidden and one output layer was used for the ANN, see Figure 3. In order to compare the impact of the number of the neurons in the hidden layer on the accuracy of camera position determination, three ANN with 10, 30 and 50 neurons in the hidden layer were created.

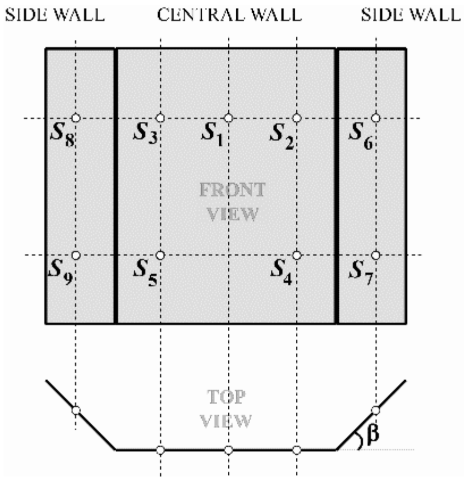


Fig. 1 Layout of the optical beacon

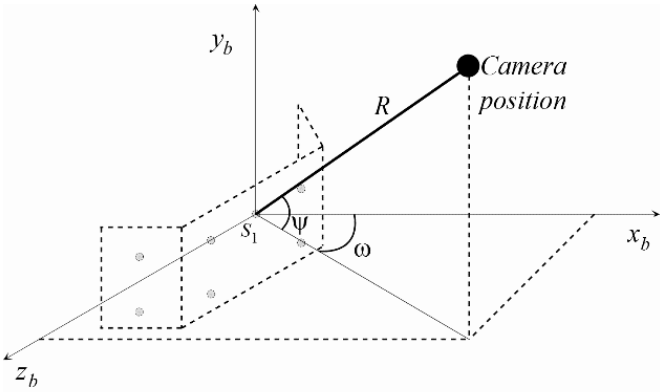


Fig. 2 Position of the optical beacon and the camera

Table 1

Range of input parameters

Distance R	0.6 m to 1.1 m, step 0.1 m
Horizontal angle ω	–30° to +30°, step 1°
Vertical angle ψ	–5° to +30°, step 1°

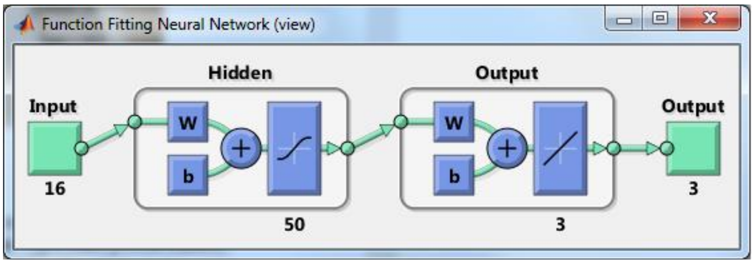


Fig. 3 Topology of the ANN

3. Experimental Verification

For experimental verification, the camera with the beacon was placed on the optical table. The distance R was changed by the camera moving relative to the beacon. The angles are set by turning the beacon around the transversal axes, see Fig. 4. Image processing and camera position determination using the ANN were implemented in the Simulink environment. Fig. 5 shows the sample of the beacon image with the detected diode positions. During the measurement, the horizontal angle ω was varied within a range of ± 30° with a 5° step and the vertical angle ψ was set to 0°, 15° and 30°. The distance R was changed in accordance with Table 1.

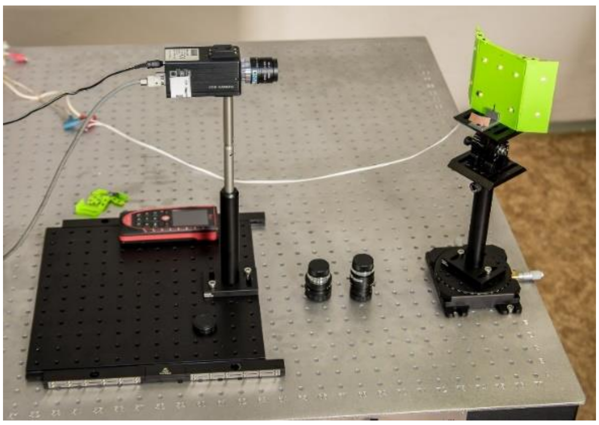


Fig. 4 Optical table with optomechanical elements

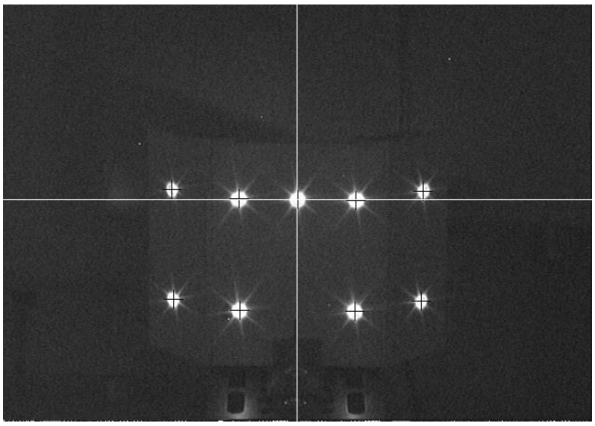


Fig. 5 Image of the optical beacon

Fig. 6 shows the example of the results in the graphical form. The angle ω was chosen as an independent variable. With the aim to improve the measurement results, corrections were made according to the following relations:

$$\omega_{mc} = \omega_m - \frac{1}{s} \cdot \sum_{i=1}^{s} \omega_{m(i)} - \omega\,; \tag{1}$$

$$\psi_{mc} = \psi_m - \frac{1}{s \cdot j} \cdot \sum_s \sum_j \psi_{m(s,j)}\;, \tag{2}$$

here s – number of R values (s = 6); j – number of ω values; ω_{mc}, ψ_{mc} – corrected values of ω_m and ψ_m.

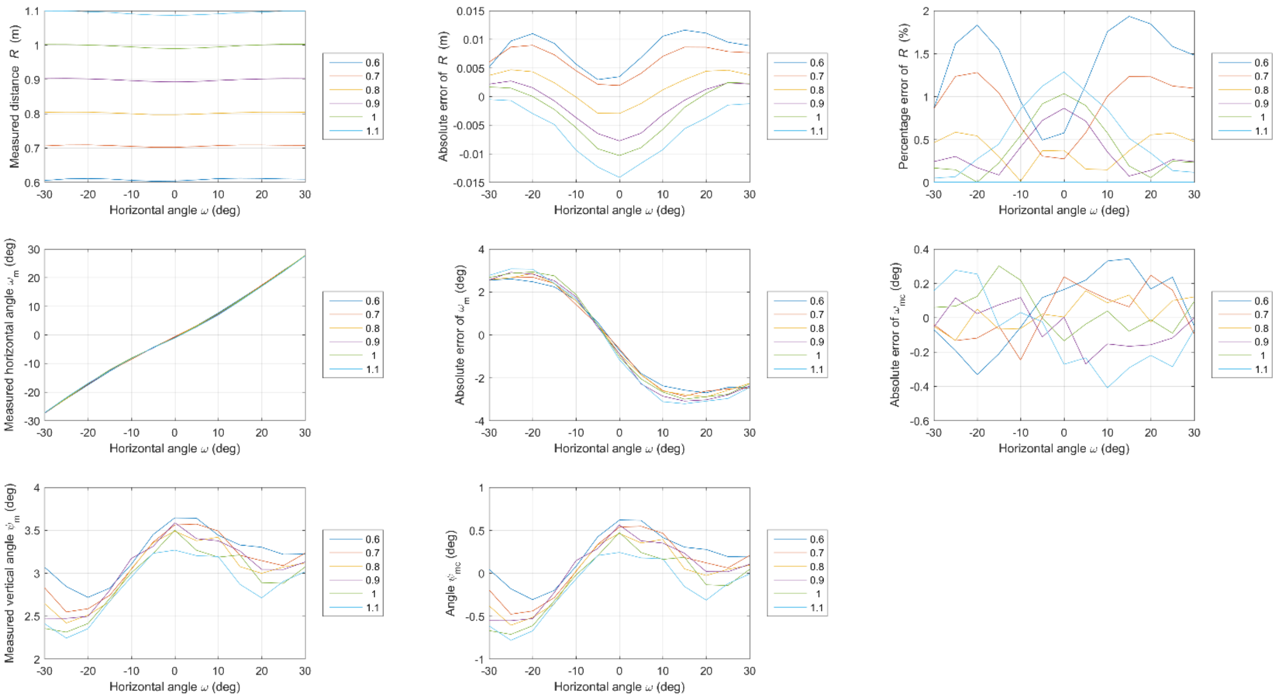


Fig. 6 Results for ψ = 0° and 50 neurons in hidden layer

The comparison of the results for individual neural networks is shown in Table 2.

Table 2

Comparison of the results for individual ANN

		Range of distances 0.6 m - 1.1 m Lens 25 mm								
		ψ = 0°			ψ = 15°			ψ = 30°		
		10 neurons	30 neurons	50 neurons	10 neurons	30 neurons	50 neurons	10 neurons	30 neurons	50 neurons
R - absolute error (mm)	average	7.66	8.87	5.12	27.27	37.34	30.73	60.15	57.06	56.64
	max	22.62	21.34	14.15	37.05	48.15	41.96	78.91	73.71	79.04
	min	0.04	0.19	0.00	7.57	25.45	21.57	36.60	22.50	29.09
R - percentage error (%)	average	0.44	0.49	0.30	1.55	2.12	1.72	3.31	3.11	3.11
	max	3.77	3.30	1.93	5.45	7.39	5.82	10.03	7.89	9.01
	min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ω_m - absolute error (°)	average	2.34	2.19	2.25	0.84	0.89	0.84	1.45	1.85	1.65
	max	3.78	3.18	3.21	2.25	2.46	2.49	4.46	4.60	4.31
	min	0.21	0.38	0.35	0.01	0.02	0.03	0.03	0.01	0.00
ω_{mc} - absolute error (°)	average	0.23	0.14	0.13	0.45	0.38	0.47	0.31	0.20	0.21
	max	0.95	0.37	0.41	1.04	0.95	1.18	1.55	0.50	0.69
	min	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01
ψ_m - absolute error (°)	average	2.83	3.17	3.03	0.94	1.01	1.25	1.21	1.53	2.06
	max	3.58	4.22	3.65	2.39	3.11	3.09	4.30	5.20	5.54
	min	2.21	2.44	2.24	0.02	0.01	0.10	0.01	0.03	0.01
ψ_{mc} - absolute error (°)	average	0.28	0.31	0.30	0.73	0.84	0.59	1.95	2.07	2.99
	max	0.75	1.05	0.78	1.45	2.10	1.84	3.37	3.67	5.15
	min	0.02	0.01	0.01	0.04	0.04	0.00	0.01	0.29	0.13

The average, maximum and minimum single errors were calculated for each ANN. The results show that the number of the neurons in the hidden layer did not have a major effect on the accuracy of camera position determination. The error rate of the distance R increased with the increasing angle ψ. However, the average percentage error of distance determination was not greater than 3.31% and the maximum percentage error was about 10%. For the angle ω, the average absolute errors before the correction ranged 0.84° to 2.34°. These errors dropped to the interval 0.13° to 0.47° after correction. For the angle ψ, the average absolute error values are 0.84° to 2.93° and 0.28° to 2.99° before and after the correction, respectively. The correction was effective predominantly for angle $\psi = 0°$ and partly for $\psi = 15°$.

4. Conclusion

The article describes the method for determining mutual positions of the camera and the optical beacon. The ANN was used to solve this task by means of the beacon's light sources. Based on the performed experiments, it can be stated that this method was successfully verified, and the errors were acceptable. The maximum errors of the angle measurements were smaller than 0.5° (for ω) and 3° (for ψ) after correction. The percentage error for distance was less than 3.31%. The position measurement resolution is given by changing the position of the light source ($S_2 \ldots S_9$) in the image by one pixel relative to S_1. It means that not only the image pixel resolution but also dimensions of the light source or beacon-camera distance may influence the position measurement resolution. This issue is not covered in this paper. Future work in this area will be focused on assessing the effect of the diodes pattern and the image resolution on the accuracy of the position measurement.

Acknowledgment

The work presented in this article has been supported by the Czech Republic Ministry of Defence - University of Defence development program "Research of sensor and control systems to achieve battlefield information superiority".

References

1. **Rullán-Lara, J.; Salazar, S.; Lozano, R.** 2012. Real-time localization of an UAV using Kalman filter and a wireless sensor network, Journal of Intelligent & Robotic Systems 65(1-4): 283-293.
2. **Kondo, H.; Okayama, K.; Choi, J.** 2012. Passive acoustic and optical guidance for underwater vehicles, 2012 Oceans – Yeosu: 1-6.
3. **Ramezani, M.; Khoshelham, K.** 2018. Vehicle positioning in GNSS-deprived urban areas by stereo visual-inertial odometry, IEEE Transactions on Intelligent Vehicles: 1-1.
4. **Mizuchi, Z.; Ogura, T.; Kim, Z. B.** 2015 Accuracy evaluation of camera-based position and heading measurement system for vessel positioning at a very close distance, 15th International Conference on Control, Automation and Systems (ICCAS): 747-751.
5. **Wang, M.; Liu, Z.; Su, D.** 2018. Accurate and real-time 3D tracking for the following robots by fusing vision and ultra-sonar information, IEEE/ASME Transactions on Mechatronics: 1-10.
6. **Saito, T.; Nomura, K.; Yamazaki, Y.** 2017. Position measurement for a mobile weed mowing robot by a camera and a laser rangefinder, 2017 International Symposium on Micro-NanoMechatronics and Human Science (MHS): 1-5.
7. **Beck, J. H.; Kim, S. H.** 2017. Vision based distance measurement system using two-dimensional barcode for mobile robot, 2017 4th International Conference on Computer Applications and Information Processing Technology (CAIPT): 1-4.
8. **Polasek, M.; Nemecek, J.** 2018. Optical positioning using neural network, 2018 41. International Conference on Telecommunications and Signal Processing (TSP), in press.

Perspective of the Use of Road Asphalt Surfaces in Tunnel Construction

J. Pokorny[1], L. Malerova[2], J. Wojnarova[3], M. Tomaskova[4], H. Gondek[5]

[1]*VŠB – Technical University of Ostrava, Faculty of Safety Engineering, Lumirova 13/630, 700 30, Ostrava – Výškovice, Czech Republic, E-mail: jiri.pokorny@vsb.cz*
[2]*VŠB – Technical University of Ostrava, Faculty of Safety Engineering, Lumirova 13/630, 700 30, Ostrava - Výškovice, Czech Republic, E-mail: lenka.malerova@vsb.cz*
[3]*VŠB – Technical University of Ostrava, Faculty of Safety Engineering, Lumirova 13/630, 700 30, Ostrava - Výškovice, Czech Republic, E-mail: jana.wojnarova@vsb.cz*
[4]*The Technical University of Košice, Faculty of Mechanical Engineering, Institute of safety and quality* Products, *Letná 9, 042 00 Košice, E-mail: marianna.tomaskova@tuke.sk*
[5]*VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Production Machines and Design, 17. listopadu 15, 708 33 Ostrava - Poruba, Czech Republic, E-mail: horst.gondek@gmail.com*

Abstract

The construction of road tunnels is nowadays topical issue in the Czech Republic and also abroad. The reasons for their construction are various, including the shortening the length of road, overcoming mountain areas, limiting traffic noise or protecting the environment. With the increasing number and lengths of road tunnels, there is also an increase of extraordinary events that occur in these buildings. Extraordinary events include fires as well. The occurrence of a fire and its expansion in road tunnels is affected by many aspects. One of the influences, that can affect the expansion of the fire and its extinguishment by fire department, is also the type of road surface. Currently, variants of concrete (cement-concrete) or asphalt surfaces are used. From the point of view of fire safety, there is a long-lasting discussion about the suitability of asphalt road surfaces in tunnel construction. The risk is seen in road flammability, in possible release of toxic combustion products, or eventually in softening caused by heat released during the fire. In past years, a number of theoretical and experimental works have been compiled, dealing with the safety of asphalt surfaces in tunnel constructions. However, the results of these works do not present clear conclusions on their safety. The advantages and disadvantages of each type of road and the expected future development are discussed in the article.
KEY WORDS: *road tunnel, fire, road surface, asphalt surface*

1. Introduction

The construction of tunnels is a complex building project, consisting of a number of elements, structures and installed equipment that allows its operation and in many cases contributes to its safety.

The European Parliament and Council Regulation (EU) No 305/2011, which substitutes Council Directive 89/106 / EEC [1], regulates conditions for the introduction of construction products onto the market. One of the conditions specifies the fire safety requirements that tunnel construction must meet. These requirements include, in the event of fire, the maintenance of the load-bearing capacity of the structure, the limitation of fire propagation inside and outside of the building, the evacuation and rescue of people and the safety of the rescue services.

In order to deal with emergency situations tunnel construction must be prepared from construction, technical and operational point of view. To meet these requirements the designer, contractor, tunnel operator and rescue worker (especially the Fire Brigade of the Czech Republic and the Police of the Czech Republic) need to cooperate.

A part of the tunnel construction is also the carriageway surface. Asphalt surfaces are perceived to be somewhat problematic.

The aim of the article is to characterize tunnel construction, to present the most important related regulations, to describe road requirements both in tunnels abroad and in the Czech Republic and to discuss the validity of existing safety standards on roads on the basis of theoretical works and experiments.

2. Emergencies on Roads and Tunnels in the Czech Republic

At present there are 26 road tunnels in the Czech Republic (see Table 1). There are three tunnels in our country that are considered to be the oldest and they are measured in tens of metres. These are the Vyšehradský tunnel in Prague, Kokořínský near Mělník and Sečský in Železné Mountains. All three of them have been built to fulfill the same purpose: to significantly reduce commuting distance and to protect valuable natural sites and historical monuments.

Pekařská brána tunnel in the Bohemian Paradise, which was built in 1914 and is only four meters long, is considered to be a rarity.

The Blanka complex, which consists of three adjoining tunnels, namely the Brusnický, Dejvický and Bubenečský tunnels, is currently considered to be the longest tunnel complex not only in the Czech Republic but also in Europe. The Bubenečský tunnel is also the longest continuously mined section of the tunnel on our country (2230 meters).

Construction of the Na Vysoké tunnel, the Suchdol tunnel, the Zámky tunnel, the Dobrovský tunnel and many others is planned in the future.

Table 1

List of tunnels in the Czech Republic [2]

Tunnel name	**Length** (m)	**Opened**	**Road**	**No of tunnels**
Radejčín	600 (L), 620 (R)	2016	Motorway D8	2
Prackovice	270 (L), 260 (R)	2016	Motorway D8	2
Blanka	5 502 (L), 5 489 (R)	2015	Ring road	2
Královopolský	1 237 (L), 1 258 (R)	2012	Road I/42 – Outer Ring road	2
Lysůvky	160	2012	Motorway D48	
Komořanský	1 937 (L), 1 924 (R)	2010	Motorway D0 (Prague Orbital)	2
Lochkovský	1 658	2010	Motorway D0 (Prague Orbital)	2
Klimkovice	1 088 (L), 1 076 (R)	2008	Motorway D1	2
Hlinky	312	2007	Road I/42 – Outer Ring road	1 two-way
Panenská	2 168 (L), 2 116 (R)	2006	Motorway D8	2
Libouchec	504 (L), 520 (R)	2006	Motorway D8	2
Valík	380 (L), 390 (R)	2006	Motorway D5	2
Mrázovka	1 298 (L), 1 264 (R)	2004	Ring road	2
Jihlava	310	2004	Road I/38	2
Zlíchovský	152	2002	Ring road	2
Husovický	585 (L), 578 (R)	1998	Road I/42 – Outer Ring road	2
Pisárecký	512 (L), 497 (R)	1998	Road I/23 – Prague flyover	2
Strahovský	2004	1997	Ring road	2
Hřebečský	354	1997	Road I/35	1 two-way
Liberecký	260	1996	Road I/35	2
Těšnovský	350	1980	Road I/35	2
Letenský	423	1953	City road in Prague	1 two-way
Sečský	40	1937	Road II/343	1 two-way
Kokořínský	24	1935	Road III/2733	1 two-way
Pekařova brána	4	1914	Road III/27926	
Vyšehradský	34	1904	City road in Prague	1 two-way

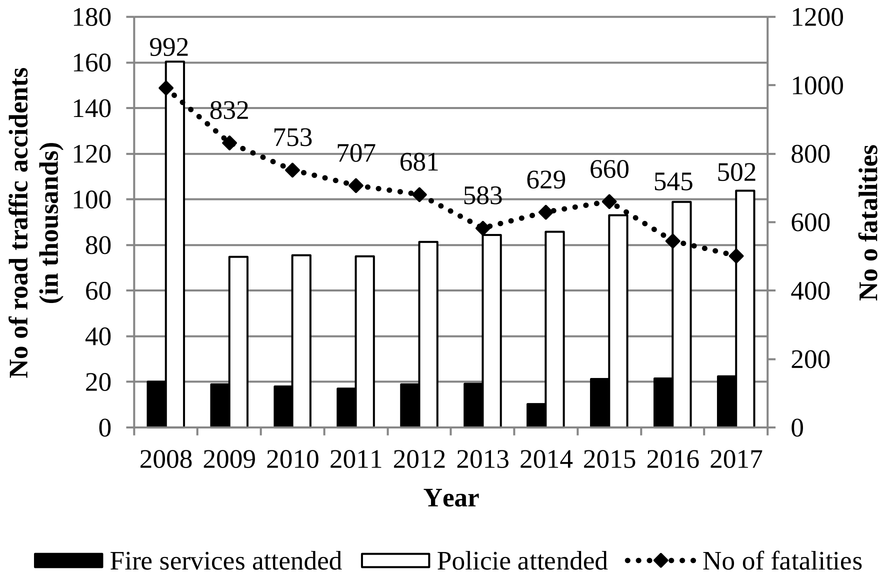


Fig. 1 Number of road traffic accidents and number of fatalities in the Czech Republic

Further issue connected with this topic is the number of road traffic accidents in the Czech Republic. The number of road traffic accidents between the years 2008 - 2017, where the Fire Rescue Service of the Czech Republic (HZS CR) and the Police of the Czech Republic had to attend, are shown in Fig. 1 [3]. The figure also shows the number of fatalities in road traffic accidents.

Fig. 1 shows that although the number of fatalities in road traffic accidents in the Czech Republic is decreasing, the number of road traffic accidents in total is increasing.

The number of fires in road tunnels in the Czech Republic between 2013 and 2017 is shown in Table 2 [3].

Table 2

Number of fires in road tunnels in the Czech Republic between 2013 and 2017

Year	**2013**	**2014**	**2015**	**2016**	**2017**
No of fires	2	1	2	2	5

Table 2 clearly shows that the number of tunnel fires in the Czech Republic during the shown period is low. However, experience with these events abroad shows that the consequences of fires can be significant. And it is the consequences of fires in tunnels that attract permanent interests from experts concentrating on tunnel fire safety [4].

3. Characteristics of Tunnel Structures

The tunnel is a linear underground throughway with roads (motorways, trunk roads or local roads), allowing for smooth and safe driving of vehicles under mountain ranges, water barriers, populated areas, culturally historical or economically valuable territories, etc. The tunnel must meet requirements of fire safety and protection of the health and safety of people (users and employees of the operator), the smooth and safe driving of vehicles as well as being economical with minimum requirements for on-site tunnel operation [5].

Tunnels can be divided by several aspects. The most important aspects are the length, type of operation and combination of length and traffic intensity [5].

Depending on the length tunnels can be divided into:

- short (100 to 500 m);
- medium (500 to 1000 m);
- long (over 1000 m) [5].

In terms of the type of operation tunnels are divided into one-way or two-way.

Depending on the combination of the length and the intensity of traffic, tunnels are divided into the following categories:

- category TA;
- category TB;
- category TC-H;
- category TC;
- category TD-H;
- category TD [5].

The extent of the safety requirements depends significantly on the classification of the tunnel in terms of the combination of length and traffic intensity. With increasing length and intensity of traffic the requirements for ensuring the fire safety conditions of the tunnel are increasing.

The construction of the tunnel must ensure smooth and safe operation, stability of the actual and surrounding environments around the tunnel, prevent surface and groundwater leaks in the tunnel area and reliably transfer all loads that act or can affect the structure. The carriageway surface is an integral part of the tunnel.

In terms of operational requirements tunnel construction longer than 350 m is classified as a structure with increased or high fire risk [6, 7]. This classification raises the need for tunnels to meet a number of fire protection requirements in their operation. Suitable types of fire extinguishers and other necessary fire protection equipment must be supplied and installed in structures such as tunnels and they are required to be kept in full operational condition and inspected and maintained by a qualified person [8].

4. Overview of the Most Important Regulations Related to the Design of Tunnel Structures in the Czech Republic

The design and operation of tunnel structures in the Czech Republic is governed by European and national legislation, Czech technical standards and technical rules issued by the Ministry of Transport of the Czech Republic. The most important European regulation is Directive 2004/54 / EC on minimum safety requirements for tunnels of the trans-European road network [9].

The most important national regulation for the fire safety of the tunnel is Government Decree No. 264/2009 Coll., on safety requirements for road tunnels longer than 500 meters [10].

Other important legal regulations that apply to the construction of road tunnels in the territory of the Czech Republic include: Act No. 133/1985 Coll., on Fire Protection, as amended [6], Decree No. 246/2001 Coll. on the

determination of the conditions of fire safety and the performance of state fire surveillance (Fire Prevention Regulation), as amended by Decree No. 221/2014 Coll. [7] and Decree No. 23/2008 Coll., On Technical Conditions for Fire Protection of Buildings, as amended by Decree No. 268 / 2011Sb. [11].

Related legal acts are Act No. 239/2000 Coll., On the Integrated Rescue System and on Amendments to Certain Acts, as amended [12], Act No. 240/2000 Coll., On Crisis Management and on the Amendment to Certain Acts (Crisis Act) , as amended [13] and the legislation that further develops them.

An important technical standard is ČSN 737507 Design of road tunnels [14] which sets out detailed rules for the design of road tunnels.

Another significant support for the design of road tunnels is the regulations issued by the Road and Motorway Directorate of the Ministry of the Interior of the Czech Republic as part of the quality policy [15]. These include, for example, technical conditions (TPs), technical conditions of the manufacturer (TPV), technical quality of construction (TKP) or technical qualitative conditions for building documentation (TKP-D).

The Combat Code of Fire Protection Units and Methodological Sheets issued by the Ministry of the Interior of the Czech Republic can also be included in the category of other regulations.

Inspirational ideas can also be drawn from the recommendations of the World Road Association (PIARC) [16] or, other foreign documents (eg design recommendations for the construction of road tunnels [17], RABT 2006, RVS 09.03.31, FEDRO 2004).

Special cases are the transport of dangerous chemicals [18].

5. Roadway and Carriageway

A roadway is referred to in the Road Act as a transport road intended for use by road and other vehicles and pedestrians including fixed street furniture necessary to ensure such use and its safety [19].

These are the following categories of roadways:

- motorway;
- trunk roads;
- local roads;
- access roads [19].

The design of the roadway is dependant on the category to which the roadway belongs. Tunnels are also part of the roadways.

A carriageway is one or more layered surfaced part of the roadway that allows, with its load bearing capacity and even surface, for safe passage of vehicles during its service life. The carriageway usually consists of five layers, the abrasion and bedding, the top and bottom sublayer and the protective layer (see Figs. 2 and 3).

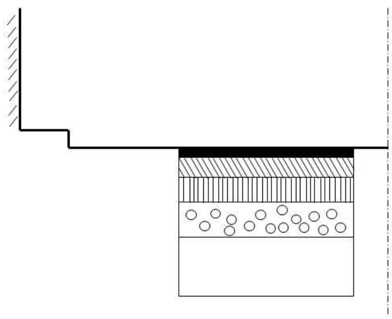


Fig. 2 Schematic illustration of the tunnel cutout

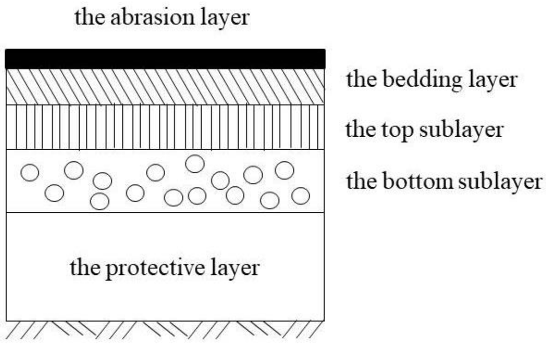


Fig. 3 Carriageway detail

Carriageway layers can be formed out of different materials such as concrete or materials held by asphalt binders [20]. Materials held by asphalt binders can also be called an asphalt mixture which differs from each other by the type and the amount of the binder, the content of the individual components in the mixture, the techniques of processing and laying. The asphalt mixture consists of two basic components, ie aggregate and binder, additives (eg organic and inorganic fibres) can also be added as well as R-material (construction waste obtained by recycling of milled bituminous surfaces).

Asphalt mixtures can be divided into:

- asphalt concrete (AC);
- asphalt concrete for very thin layers (BBTM);
- very soft asphalt mixture (SA);
- bituminous hot melt mixture (HRA);
- asphalt carpet mastic (SMA);
- poured asphalt (MA);
- asphalt carpet drainage (PA) [20].

Concrete and asphalt carriageways can be utilized in the construction of road tunnels.

6. Carriageway Requirements of Tunnels in the Czech Republic

There are a number of building, operational and safety requirements on tunnels. Construction requirements include the use of suitable materials (see also chapter 5), incline, drainage, etc. Another requirement for top layers of the carriageway in tunnels is to apply non-glossy and bright finish. On the contrary, on the access roads to the tunnel complex, the brightness is reduced by the use of dark and non-glossy surfaces on the carriageway, the portal and the walls of the terrain cut out.

The operational requirements include long-term service life without maintenance (closure of tunnels due to maintenance is problematic), low noise (especially in urban tunnels).

From the fire safety point of view two issues arise when using asphalt carriageway; the issue of "contribution to fire intensity" and "softening of the carriageway surface in a fire" (softening of the carriageway may make intervention by rescue units more difficult).

Due to these issues the use of asphalt carriageways in tunnels has been restricted in the Czech Republic. Carriageway construction is determined on the basis of a fire safety and technical-economical assessment, with tunnels with a cement-concrete layer being recommended for medium tunnels, and required for long tunnels. [5].

7. Conclusions from Partial Research on Asphalt Carriageways in Tunnels

In recent years several firefighting experiments have been carried out concerning fires in tunnels. The flammability of the asphalt mixture was examined rather marginally. Examples of asphalt mixes include the experimental study of the behavior of asphalt by combustion carried out by A. Noumowe of Cergy-Pontoise University in France, or research aimed at characterizing the behavior of typical asphalt roads in a tunnel fire which was implemented in the BRE Centre for Fire Safety Engineering, University of Edinburgh, Great Britain [21]. Other important experiments include large-scale tests conducted in the Runehamar Tunnel [22].

It is clear from the experiments that the asphalt carriageway surface can be ignited by the heat flow density of 40 $kW.m^{-2}$. Typical asphalt samples heated by the standard temperature curve ignited at 480 to 530 ° C [21]. In addition, constructional structures in tunnels are generally rated by curves other than the standard temperature curve. These are RABT or RWS curves, which assume a very intense fire development and hence reach high temperatures in a short time. The temperatures given by the curves described are closer to the temperature of the hydrocarbon curve than to the standard temperature curve [23].

Softening of asphalt carriageway surfaces were evaluated in relation to the real experiments conducted in the Runehamar Tunnel in 2003. The heat outputs were 75 kW, 150 kW and 200 kW. The importance of softening of asphalt mixtures combined with the possible "sinking" of the firefighters must be evaluated in the context of the distance from which firefighters can intervene. This distance is influenced by fire conditions, technical possibilities and tactical fire brigade procedures. During the experiments, the heat flow density at a distance of 10 m from the focal point of the fire was approximately 4 to 12 $kW.m^{-2}$. These heat flux densities may, of course, cause softening of the asphalt. However, temperatures at the distance of 10 m exceeded 400° C, which is problematic in terms of implementation of the intervention. Somewhat less severe exposure was obtained by computer modeling, however, this is largely dependent on the size of the fire [24, 25].

Certain information on softening of the asphalt carriageway surface can also be obtained from the calculations made by Kasa [20]. The development of the fire was characterized by a hydrocarbon temperature curve. Temperatures were monitored in the two upper layers of the carriageway. Given the assumption that the asphalt mixture consists of aggregate and only about 5% of the binder, the thermal and technical characteristics of the aggregate were assumed. The surface temperature of the carriageway was approximately 200° C in the 60^{th} minute of the fire, and it is not possible to assume the ignition of the asphalt mixture. However, asphalt softening occurred (softening temperatures of conventional asphalt mixtures used on roads are generally below 100° C, see [26]).

8. Discussion

Asphalt road surfaces in tunnels give rise to permanent safety issues from the point of view of fire safety, which relate to the possible contribution to the intensity of the fire and the difficulty of the intervention of the fire units due to their softening.

The tragic events that took place in the tunnels (eg Mont Blanc, the Tauern tunnel, the St. Gotthard tunnel, the Fréjus tunnel) have led in some countries to the lower use of asphalt carriageways in road tunnels. The Czech Republic is one of these countries. To clarify, it should be noted that there are no uniform regulations within the European Union as to the suitability or inappropriateness of asphalt carriageways in tunnels.

It is clear that the behavior of asphalt surfaces in fires is significantly affected by the composition of the asphalt mixture.

The experiments presented in this paper show that asphalt surfaces are flammable at relatively low thermal outputs, ie from 40 $kW.m^{-2}$, and flashpoint at 480 to 530 ° C. At the same time it has been confirmed that asphalt surfaces contribute to a certain degree to the fire intensity. The subject of the discussion is how important is this contribution in relation to the overall intensity of the fire.

The issue of softening of asphalt surfaces and possible disruption of firefighting is even more problematic. As it

has already been stated, the importance of softening of asphalt mixtures associated with possible "sinking" of firefighters must be assessed in the context of the distance from which the firefighters will be able to intervene. Although the measured heat flux densities at real distances of firefighters' intervention from the projected fire source, ie 10 metres or more, indicate that the fire intensity is likely to be low enough that asphalts will not ignite, but their softening has not been refuted by experiments or calculations. To a certain extent, the fact that the assumed bitumen surface layer generally does not exceed 50 m, the possible "sinking" into the asphalt mixture is not likely to be a fundamental factor.

In the Czech Republic, asphalt mixtures have been examined from the point of view of safety as part of the Czech Republic's Technology Agency TA04031642 Asphalt in road tunnels project. Although the project was completed in 2017, no results have yet been published to answer these questions unequivocally.

Due to the current knowledge gained from the experiments and calculations, it is not possible to respond unequivocally to safety issues in the use of asphalt roads in tunnels. Resolving the contribution of asphalt surfaces to fire intensity and solving problems of firefighters "sinking" into the asphalt requires further research. For experiments, it seems advisable to recommend experiments using the Taguchi approach [27].

9. Conclusion

The possibility of using asphalt road surfaces in road tunnels has been discussed by experts in safety for a long time. Considerable contribution to fire intensity and possible softening of asphalts is considered to be problematic, which may make it more difficult for firefighters to intervene.

Realized experiments and calculations do not provide clear answers to these problematic areas. To assess the impact of asphalts on tunnel fires, further research is needed.

In this context, the requirement for regulations in some countries, for example also in the Czech Republic, is justified in making road surfaces with a cement concrete cover.

Acknowledgements

This work was supported by the Ministry of the Interior of the Czech Republic, project no VI20162019034 Research and development of established models of fire and evacuation of persons and their practical application to assessment of fire safety of buildings.

Reference

1. The European Parliament and Council Regulation (EU) No 305/2011 dated 9th March 2011, which substitutes Council Directive 89/106 / EEC [1], regulates conditions for the introduction of construction products onto the market. [online quotation: 2018-04 -21]. Available at: https://eur-lex.europa.eu/legal-content/CS/TXT/?uri=CELEX%3A32011R0305
2. Tunnels in the Czech Republic. Motorway - Road.cz [online quotation: 2018-04-29]. Available at: http://www.Motorway-Road.cz/tunel.htm
3. Statistical Yearbooks of the Fire Rescue Service of the Czech Republic [online quotation: 2018-04-29]. Available at: http://www.hzscr.cz/clanek/statisticke-rocenky-hasicskeho-zachranneho-sboru-cr.aspx
4. **Kavan, S.** Ethical Aspects of the Work of Rescuers During Extraordinary Events. In The Social Sciences, Volume 10, Issue 6. Medwell Journals, 2015, pp. 684-690. ISSN: 1818-5800. Available at: http://medwelljournals.com/abstract/?doi=sscience.2015.684.690
5. ČSN 737507 Design of road tunnels. Prague: Office for Standards, Metrology and Testing, 2013. p. 49.
6. Act No. 133/1985 Coll., on Fire Protection, as amended [online quotation: 2017-07-2]. Available at: https://www.zakonyprolidi.cz/en/1985-133
7. Decree No. 246/2001 Coll., on determination of conditions of fire safety and performance of state fire surveillance (Fire Prevention Order), as amended by Decree No. 221/2014 Coll. [online quotation: 2017-06-10]. Available at: https://www.zakonyprolidi.cz/en/2001-246
8. **Mračková, E.; Chromek, I.; Tereňová, Ľ.; Marková, I.** Protection against fire. Skriptum, 1st issue, Zvolen: Technical University of Zvolen, 2017. 365 s. ISBN 978-80-228-2998-4.
9. Directive 2004/54 / EC on minimum safety requirements for tunnels in the trans-European road network [online quotation: 2018-04-21]. Available at: https://eur-lex.europa.eu/legal-content/CS/TXT/?uri=LEGISSUM%3Al24146
10. Government Order No. 264/2009 Coll., on safety requirements for road tunnels longer than 500 meters [online quotation: 2017-07-2]. Available at: https://www.zakonyprolidi.cz/cs/2009-264/zneni-20090901
11. Decree No. 23/2008 Coll., on Technical Conditions of Fire Protection of Buildings, as amended by Decree No. 268 / 2011Sb. [online quotation: 2017-07-2]. Available at: https://www.zakonyprolidi.cz/en/2008-23
12. Act No. 239/2000 Coll., on Integrated Rescue System and on Amendments to Some Acts, as amended [online quotation: 2017-07-2]. Available at: https://www.zakonyprolidi.cz/en/2000-239
13. Act No. 240/2000 Coll., on Crisis Management and on Amendment to Certain Acts (Crisis Act), as amended [online quotation: 2017-07-2]. Available at: https://www.zakonyprolidi.cz/en/2000-240
14. ČSN 737507 Design of road tunnels. Prague: Office for Standards, Metrology and Testing, 2013. p. 49.
15. Quality of road infrastructure policy. [online quotation: 2018-04-21]. Available at: http://www.pjpk.cz/

16. World Road Association | PIARC. [online quotation: 2018-04-21]. Available at: https://www.piarc.org/en/
17. **BARK, A. et al.** Entwurfstechnische Empfehlungen für Autobahntunnelstrecken. Bremen: Fachverlag NW, 2015. ISBN 978-3-95606-210-0. [online quotation: 2018-04-30]. Available at: http://edok01.tib.uni-hannover.de/edoks/e01fn16/867778741.pdf
18. **Malerova, L.; Pokorny, J.** 2017. Transport of Dangerous Substance in Territory. In: Proceedings of the 21st International Scientific Conference Transport Means 2017. Lithuania: Kaunas Univ Technology Press, pp. 607-610. ISSN 1822-296 X (print). ISSN 2351-7034 (online).
19. Act No. 13/1997 Coll., on Roads, as amended [online quotation: 2018-04-26]. Available at: https://www.zakonyprolidi.cz/en/1997-13
20. **Kasa, J.** Problems of flammability of bituminous surfaces (asphalts) on road tunnels in the Czech Republic [online quotation: 2018-04-26]. Available at: http://people.fsv.cvut.cz/~wald/edu/134SEP_Seminar_IBS/2012/06_SP12_Kasa_Zivice.pd
21. **Carvel, R.O.; Torero, J.L**. 2006. The contribution of asphalt road surfaces to fire risk in tunnel fire: Preliminary findings, In: Edinburgh Research Archive. The University of Edinburgh, [online quotation: 2012-10-24]. Available at: https://www.era.lib.ed.ac.uk/bitstream/handle/1842/895/Carvel%20Torero%20Hong%20Kon;jsessionid=F1F323A8F25A2DE73E34343958E27CC7?sequence=1
22. Summary of Large Scale Fire Tests in the RUNEHAMAR Tunnel in Norway [online quotation: 2018-04-29]. Available at: http://www.vegvesen.no/_attachment/61890/binary/15101
23. EN 1991-1-2 Eurocode 1: Structural loads - Part 1-2: General loads - Load of structures exposed to fire. Prague: Czech Standards Institute, 2004. p. 55.
24. **Mozer, V.** 2017. Fire safety in tunnels forming part of critical infrastructure, In: Proceedings of the 47th Annual IEEE International Carnahan Conference on Security Technology, Colombia, Universidad de Antoquia. pp. 256-260. ISBN 978-958-8790-65-7.
25. **Mozer, V.** 2013. Modelling fire severity and evacuation in tunnels, In: Communications – Scientific letters of the University of Zilina, 15(1), Zilina, University of Zilina, p 85-90. ISSN 1335-4205.
26. EN 12591 Bitumen and Bituminous Binders - Specification for road asphalt. Prague: Office for Standards, Metrology and Testing, 2009.
27. **Blecharz, P.; Štverková, H.** 2017. Consumer preferences in terms of quality and price. 18th - 19th May 2017, Ráztočno (Handlová). University of Economics, Bratislava, Faculty of Business Management, Department of Business Administration. pp. 105-111.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Business Risk Management at Transport Companies: Lithuanian Study Case

A.Jarašūnienė[1], N.Batarlienė[2], K.Čižiūnienė[3]

Vilnius Gediminas Technical University,Plytines Street 27, LT-10105 Vilnius, Lithuania
E-mail:[1]aldona.jarasuniene@vgtu.lt, [2]nijole.batarliene@vgtu.lt, [3]kristina.ciziuniene@vgtu.lt

Abstract

The article deals with the concept of risk of operation of transport enterprises, presents the types of risks, and analyzes business risk management. From the scientific point of view, the risk issues have not been sufficiently well investigated so far. In order to successfully manage or control any transport activity, it is necessary to determine the degree and extent of risk. The article defines the terms “risk”, “risk management” and other relevant concepts in this field, that risk management is one of the modern working methods that are important not only for transport companies but also for other organizations and other companies. The paper presents an analysis of the results of the empirical research, identifies the main risk reduction measures, and presents the essential risk reduction of the risks – the implementation of the Lean System and the adaptation of the Outsourcing system to the transport company.
KEY WORDS: *risk, risk management, ways of risk reducing*

1. Introduction

Each legal entity faces various risks in the course of an activity. Without a risk would not be: competition, innovative business ideas, incentive to improve and diversify business. At present, for most companies, under the conditions of a perfect market, there is a risk: introducing a new product or service, improving business, establishing new relationships with customers and suppliers, attracting a new customer segment or expanding the geography of the business [4]. Risk could be managed only after a thorough analysis of the causes of the potential risk, the ways of reducing it, through stakeholder surveys. Low focus on business risks, mismanaged management measures, or actions that are usually not timely can lead to a financial deterioration of the company, large losses and even bankruptcy [10]. In Lithuania, almost all enterprises operate in conditions of perfect competition, and in order to remain in the market they must expand, invest in innovations, establish new relationships, i.e. take the risk. According this reason, it is necessary to consider business risk aspects in practice and improve management algorithms.

Over the past year, it was interested in risk management and it’s used in enterprises and organizations, but from a scientific perspective, the risk issues have not been sufficiently well investigated, especially in transport companies. This can justify the novelty of the article.

The aim of the paper is to present the opportunities for the risk, analyze the business risk phases, management methods, after the research, identify the risks to which transport companies are exposed, analyze the aspects of risk management applied in the transport business and present business risk mitigation.

In the economy, the risk is associated with business risk, which is the likelihood of potential losses or loss of revenue compared to the one adopted in the business plan, which provides for the rational use of resources. Also, the risk is inseparable from dangerous working conditions, i.e. possible risks of harmful factors related to the nature of the job, and set the permissible thresholds below which the working environment is considered safe and harmless, matching [20]. The next most important factor of risk in transport companies is the management of human resources, which ensures the competitiveness of the company [6].

2. Business Risk Analysis from a Theoretical Point of View

Business risk is described as the probability of potentially potential losses compared to the planned option for rational use of resources. Different authors define business risks differently. Risk is a multifunctional concept that can be used in different contexts, in different situations and areas [4; 22]. The word risk is so used in today’s life that it can be kept as everyday concept [12].

Risk is a situation where business representatives are not aware of a possible outcome, but the consequences can be foreseen [3]. Authors examining the possible consequences of risk and uncertainty on business profitability found that uncertainty affects portfolio returns more than risk [3].

Other author states that business risk is the probability of a loss of business or loss of income compared with the one provided for in the business plan [14].

Duxbury and Summers based on their own research, assume that entrepreneurs are more inclined to take higher risks in investing in innovations and improvements, especially in a volatile, volatile market, with higher risks in this environment, but also a high probability of profitability [9]. The authors argue that in order to better analyze and determine the relationship between market and profitability, the emerging and falling markets need to be analyzed as much as possible [9].

According to Garškienė, business risk is the risk associated with the production of product, the sale of goods and services, financial transactions, material, labor, financial, informational (intellectual) resources used in economic activity, with their total or partial loss [13].

Business risk is described as the probability of potentially potential losses compared to the planned option for rational use of resources. The size of the loss, compared with a certain chosen base, will show the degree of economic risk. To assess the degree of risk, the base may be total costs, expected income, expected profit, etc.

The term "risk" itself has two main meanings:

- Potential danger, imminent harm and disaster;
- Functioning in the hope of success.

Both of these meanings apply to business risks and this complicates the analysis of this phenomenon. In describing business risk, we need to allocate:

- The dangers, uncertainties, and uncertainties that exist in the market economy itself (because the market itself is volatile, with constant fluctuations, it creates hazardous situations);
- Reaction of market participants: they tend to take risks, "trust" the risk of falling into the market or avoid it [13].

In economics, the risk often associated with uncertainty, this view is shared by such authors as Laskienė, Snieška [15], Rejda [18] and others. The authors note that risk is the uncertainty associated with an unpredictable event. Aleknavičienė thinks that the concepts of risk and uncertainty are inappropriate for separation [1]. According to her, there is a possibility of a result of one and the other, and whether the information available is reliable, whether it is sufficient or whether it is complete depends only on the degree of reliability of the expected results.

It can be argued that business risks are not confined to accidents, technological errors or insufficient commercial or managerial experience. Different risks are perceived by individual business team members: customers, lenders or managers. Different authors differentiate the risk factors.

There are authors who define financial risk by several statements:

- Possibility of changing the expected future results.
- The possibility of financial losses.
- Deviation of the actual results from the expected.
- Inconsistent results.

The authors Nedzveckas and Rasimavičius define the risk as losses that occur when the target is not achieved [17].

A risk event will be called an event that has a certain probability that will negatively or positively affect the stated purpose of the business activity. Risk management is the identification of risk events, quality and quantity analysis, planning, control, response and documentation [8].

The risks to the company in the transport world could be relatively internal and external. External unpredictable risks are unforeseen governmental regulatory decisions, natural phenomena, crimes, unexpected external ecological or social effects. Predictable but not foreseen external risks: market changes, negative social consequences, exchange rate changes, uncounted inflation, changes in tax system. Internal non-technical risk: deviations from work plan and workforce, lack of materials, delays in supply, excess of funds available, etc.

Internal non-technical risk: deviations from work plan and workforce, lack of materials, delays in supply, excess of funds available, etc.

Technical Risk: Technology Change, Quality Improvement Related to Project Execution; specific risks of the technology used in the project.

Legal risks: licenses and patents, non-performance of contracts, court proceedings with external partners, internal legal proceedings.

The insured risks: direct damage to property; indirect losses related to the conversion of equipment, etc.; the risk is insured by the normative documents for other persons; co-workers' insurance. Insurance is one of the main ways of reducing risks in transport companies.

Transport companies' significant economic risks associated with international trade transaction participants' willingness and capacity to meet its obligations.

Economic risk can be divided into 5 different risks:

1. Market risk is the risk of sales in the broadest sense associated with the markets for exported goods. The goods produced for export may not be sold, for example, if new competitors have appeared or if the forecasted sales prices are no longer in line with the world price level; if new customs duties arise; if the quality of the product does not match competition; if the exchange rate has changed, etc. Constant market monitoring is therefore a necessary, but not a sufficient condition for hedging.

2. The risk of acceptance (sale) of goods. This risk means that a foreign buyer may not accept ordered goods. Sales risk can occur both in the production of the product and in the delivery stages: during the product stage, some events may prevent the manufacture or dispatch of the goods. For example: an importer may refuse an international transaction; the importer was not able to pay due to the bankruptcy; the importer discontinues payment (partially or totally) because of the liquidity problems due to the difficult economic situation; at the supply stage, i.e. when goods have already been shipped, there is a risk that the importer will not accept ordered goods.

3. Transport risk is the risk occurring during the supply phase of the exported goods. The risk of transportation

arises from possible damage to or loss of goods during transportation [5].

4. Common credit risk arises if the payment (full or partial) is not received or delayed. In addition to the main requirement to pay for exported goods, credit risk also includes the risk of potential redress. Credit risk arises when the importer cannot pay. In economic literature, the inability of an importer to pay sometimes is a solvency risk due to a long-term insolvency of the client, although he was initially thought to be paying off. Insolvency can be caused by bankruptcy, deteriorating economic situation.

5. Guarantee credit risk. In order to reduce the risk of an international transaction, the exporter may demand guarantees. Guarantees are generally provided by credit institutes, but they can also be provided by non-banks. Credit risk to a certain extent can be insured in the following ways: advance or advance payment, letter of credit, guarantees, export insurance, factoring or forfeiture [21].

The authors list a number of business risk factors that depend on many factors, both external and internal.

2.1. Business Risk Management

The activities of companies operating under market economy conditions are dynamic, therefore risk and management are an integral part of business. The external and internal environment is constantly changing, which is associated with operational uncertainty, inaccurate performance outlooks, and risky solutions. Environmental volatility raises the need for risk management. It is worth noting that the issue of risk management is a low-paying economic aspect, which affects not only the financial sphere of the country but also other areas of public life.

Risk avoidance is not possible, but it can be managed using a variety of methods and tools that will help predict the occurrence of a negative event and reduce its negative consequences [19].

Beasley and others states that business risk management is not a passive process that gives an enterprise the ability to risk, it is a set of tools, different methods, management modes that will guarantee a minimum deviation of performance from predicted. In other words, it is a process that involves not only different measures, but also ways to realize them, which minimize the impact of adverse effects on performance [7].

Risk management is treated as a structured approach to uncertainty and its management. Five risk management steps are identified: risk identification, risk analysis, prioritization, risk reduction and risk monitoring.

Risk identification – this is the first step in identifying specific risks. This includes a list of all potential risks that could negatively affect the company's operations.

The risk analysis stage assesses the probability that the relevant risk will arise. It also assesses the impact that these poses. Certain measures are used to reduce the risk or the likelihood of a risk occurrence. Each of these costs is costly, and often very unprofitable. It is therefore appropriate to set priorities for each risk from the identification stage.

The fourth stage of risk management is the reduction of risk. The latter phase involves risk elimination. If it is not possible to completely eliminate the risk, then plans are being made at this stage that will reduce the likelihood of a specific risk.

The last phase of risk management is risk monitoring. For effective enterprise management and operational success, it must carry out regular performance monitoring.

Summarizing the theoretical concepts of business risk management, it can be argued that this is a multi-level process that requires the attention of the entire company team. Therefore, all risks should be foreseen.

2.2. Ways of Business Risk Reduction

Risks in companies are practically inevitable, but they can be managed in order to reduce the magnitude of potential losses. It is best to apply the following economic risk mitigation measures: to increase the effectiveness of the strategic plan, to share risk between company executives and business partners, to insure a business, to have a cash reserve, to raise staff qualifications, to quickly adjust the company’s business lines, to have alternative solutions, etc. [16].

After assessing the potential risk of an enterprise, the manager of the company must make the following decisions:

Risk transfer. Risk reduction is reduced by transferring it to a person or organization that can effectively solve the problem. It is possible to reduce the risk by insuring it in the insurance company.

Postponement of risk. Risks can be delayed when work is lifted when negative effects can be eliminated.

Risk reduction. This includes the possibility of a risk manifestation or a reduction in potential exposure.

Risk taking. Some risks can be assessed and absorbed and neutralized. In this case, a further work plan is prepared by assessing the changes made by the risk exposure.

Elimination of risk. The identified risk factor can be eliminated. This operation requires additional costs, but they are not high compared to the total value of the company.

Diversification. Investment diversification is a risk management tool that helps to reduce the risk of a portfolio of securities (an investment portfolio) that the investor plans to acquire or has acquired [2].

Distribution of risk. Risk is distributed at project preparatory and contracting moment. It should be remembered that the greater the risk the participants will want to transfer to the investor, the harder it will be to find it.

Transport companies need to anticipate, assess and reduce not only internal and external environmental risks but much more attention must be paid to the company’s finances: costs and profits. The competitive environment,

customers' purchasing power, their desires and needs must be analyzed in detail, the range of services must be constantly improved.

3. Analysis of Empirical Research Results

The purpose of the empirical research is to determine the risks to which transport companies are exposed, to analyze the aspects of risk management applied in the activities of transport enterprises. Questionnaires were sent to transport companies. 290 road transport companies were selected for the risk assessment and analysis.

After completing the survey, 55% of responses were achieved (out of 290 selected transport companies, 160 respondents answered the questionnaire).

According to the formula, the reliability of the survey of transport companies was calculated.

$$\Delta p = t\sqrt{\frac{w(1-w)}{n}\left(1-\frac{n}{N}\right)}, \tag{1}$$

here t – coefficient of reliability; Δp – deviation of random not repeated selection boundary part; w – the average of the alternative attribute; n – number of featured selective population units; N – number of selective population units.

Deviation of random not repeated selection boundary part has been selected 10%, this is $\Delta p = 0{,}1$.

Separate units of a sample population are respondents who participated in the survey. In our case, there are 160 respondents. Selective population units are all eligible enterprises, in this case 290.

In order to calculate the reliability of the survey, the average of the alternative attribute must first be determined:

$$w = \frac{n}{N} = \frac{160}{290} \approx\sim 0{,}552 = 0{,}55\,. \tag{2}$$

Next the reliability of the survey results of transport companies can be calculated:

$$0{,}1 = t\sqrt{\frac{0{,}55(1-0{,}55)}{160}\left(1-\frac{160}{290}\right)}, \tag{3}$$

$$t \approx 1{,}2 = 1 \tag{4}$$

Since $t = 1$, reliability is $P = 0.693$. Therefore, it can be stated that the answers of 160 respondents correspond to 290 respondents' opinions - 70%.

The questionnaire was composed of closed and open questions. It was wanted to find out the current situation and the causes of the risks that affect transport companies.

The first question for respondents – do companies pay more attention for management of transportation risk than 10 years ago? All respondents answered positively. In their opinion, it was influenced by:

- Insurance.
- Park renewal.
- Specificity of cargo.
- Unaffordable risk factors that cost a lot for companies.
- Loss reduction.
- The market and its regulatory changes.
- Increased competition.

When respondents were asked what they think about who should be responsible for the risk management of transport companies – the majority of respondents believe that the main responsibility should be logistics (supply) manager. As a manager, he manages the orders of the company, plans, organizes and cares about the storage, transportation and provision of goods and materials, customer service. Respondents also believe that most of the responsibility has to take the company directors, senior management and risk control manager (internal). Companies do not tend to hire additional employees (a third person).

Respondents were asked to indicate which of the five factors threatened the transport companies, ranging from 1 to 5 (1 very often, 2 – often, 3 – normal, 4 – rarely, 5 – very rarely) (Table 1).

We can see from the answers that the lack of workforce is the greatest threat to transport companies (average coefficient of respondents 2). Other threatening factors are related to financial risk – payments delays and increased prices of raw materials (average factor of respondents 2.3). The respondents consider the less threatening to be carriers' mistakes (average coefficient of respondents is 2.6). The least threatening factors are decreasing of market, restriction of export/import, production errors and natural disasters (average respondents' ratio 3.2–4).

According to all respondents, external factors having the greatest impact on transport companies are economic downturn, market shrinkage. The economic downturn is a decline in total production, income, employment and trade, which usually lasts for half a year, covering many national economic areas and causing their disruptions. Respondents

also believe that political disagreements, such as political tensions between countries, and the limitation of international trade are also contributing (Fig. 1).

Table 1

Factors threatening transport companies

Factor	Evaluation
Decreasing of market	3,2
Restriction of Export / Import	3,6
Increased prices of raw material	2,3
Supplier's mistakes	3
Production errors	4
Carrier mistakes	2,6
Natural disasters	4
Lack of workforce	2
Payment delays	2,3

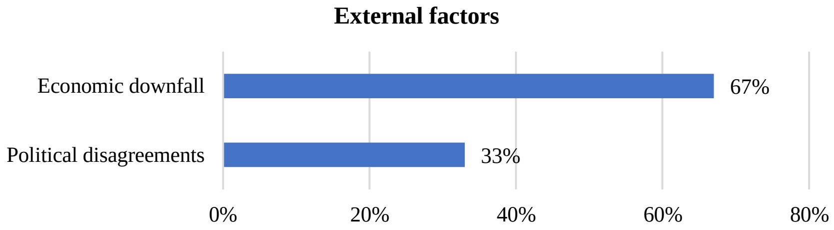


Fig. 1 External factors having the greatest impact on transport companies

Internal factors that have the biggest impact on transport companies: carriers' mistakes make up 29%. The most common carriers mistake is the verbal agreement only. In some cases, the carrier does not obtain a mandatory cargo package even if it is described in the contract. In this case, the client refuses to pay until all documents are submitted. As a result, the carrier must return to the consignor and look for documents (Fig. 2).

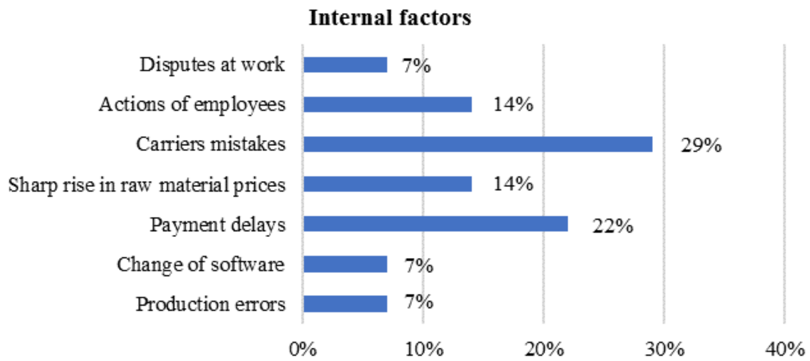


Fig. 2 Internal factors with the greatest impact on transport companies

According to the respondents, the most commonly used transport company risk management actions are risk management – insurance risk limitation – 28%, analysis of past events – 28%, change of market – 26%, annual risk management plan – 9%, experience of other organizations – 8% (Fig. 3).

Fig. 3 The most commonly used actions on the transport company's risk management

According to respondents, the best solutions to improve enterprise risk management are:

- Personnel training – 33%;
- Improvement of the company – 42%;
- Application of technologies – 25%.

According to respondents, the main resources and attention should be focused on internal and external environmental analysis and risk identification. In their view, effective measures cannot be taken without identifying the risk that can have the greatest impact.

According to respondents, what efforts should be made to reduce the risk, was answered that – prevention or disposal. Everyone said that it would be best for transport companies to take risk prevention by pre-rating potential threats. Some respondents think that some attention should be paid to preventive actions, but at the same time they are ready to deal with the consequences.

4. Measures of transport companies risk management

Summarizing the results of the research, it can be argued that small and medium-sized transport companies often do not have any risk management mechanism, often risk is not managed at all, their impact and probability are not evaluated. In small and medium-sized enterprises, the evolution of risk management is not well advanced; the main risk management tool is insurance, but only part of the risk is managed in this way.

Risk management and process optimization in a company is a mature business indicator. The main problem for small and medium-sized transport companies is the fear of responsibility. Therefore, it is often the aim of avoiding risk, although, often, risk aversion hinders the development of a transport company and is not exploited. Many of the risks come from unprocessed processes, so it's important to stabilize business. Rules, regulations, distribution of functions stabilize the company's activities. Risk reduction is a complex process. Reducing risk may also require managing many other business processes.

In summary, it should be emphasized that all risk management is initiated internally. There are a number of operational risk management elements that are vital for each transport company: managers must provide tools for responding to changes in the situation, managers should clearly allocate responsibilities to employees, there should be a clear definition of employee functions in the company, internal control and rules also are required.

One of the possible risk management options that is appropriate for small and medium-sized enterprises is the creation of a portfolio of risks [11]. This method allows a comprehensive analysis and evaluation of the risks they face and effectively to provide for appropriate measures in response to the risks.

The risk elimination and mitigation measures consist of the following steps:

- the acceptability of a risk assessment;
- assessment of risk reduction opportunities;
- choice of risk reduction methods;
- risk reduction options;
- feasibility assessment and choice of risk reduction options.

After selecting a range of measures to eliminate or reduce the risk, it is necessary to decide whether the chosen measures are of an adequate level.

One of the ways to reduce the risk is to apply the Lean system and adapt the Outsourcing system to the transport company.

4.1. Lean System in the Transport Sector

The Lean system can be successfully deployed not only in companies operating in the manufacturing sector. The application of the Lean system is also popular in transport companies with the aim of providing specific services. Lean system principles are as follows: elimination of unprofitable business processes; acceleration of process; reduction of resource; liquidation of mistakes; providing clarity and accuracy to processes.

The Lean system in the transport services sector helps to solve many problems. First of all, the Lean system ensures that services are provided to a person at a fixed, agreed time. Frequently, service providers fail to observe certain terms, so that recipients of services can find another service provider that is more in line with their needs. As a result, the Lean system helps speed up processes and save existing customers. Lean also supports the one window principle in the service sector. This means that all the necessary information can be obtained from a single worker rather than standing in queues and receiving different kinds of information from different employees. It is also important that the Lean system in the transport sector helps to avoid problems such as inaccurate or inaccurate information provided to customers, the provision of inappropriate services, lack of response to customer complaints and other issues.

The Lean system is successful because it helps to reduce the cost of your organization's products or services. This system also helps to effectively reduce the execution time of the order, as the entire process eliminates waste. The Lean system is successful because it ensures the quality of the operation as well as the responsibility of the staff. The Lean system is based on two aspects: data analysis and economic impact calculation.

The Lean system is based on five basic principles. The first is the value. The value is what the client pays for. The second principle is the value flow. According to this principle, it is necessary to establish a plan for all processes, identify specific actions and eliminate those who do not create value. The plan must contain only value-creating actions.

All this is done, orienting and thinking about the benefits to the customer. The third principle is the flow of traffic flow, in which there are no remaining processes that do not create value. It goes without interruption. The fourth principle is pulling. In line with the position that the main benefits to the customer, simplify the logistics supply chain. The fifth principle is improvement. Improvement is understood as a priority for the successful completion of the first-ever, based on continuous improvement.

In order for the Lean system to benefit the company, the company must abandon its traditional approach to process management and completely change its course of action. In order to adapt the Lean system to the management of the transport company's processes, the following innovations need to be implemented: change of leader-ship thinking and values; change of management methods; substantial change in the company's operating principles; implement other forms of improvement and education.

The directional change strategy applies the top-down principle. This principle means that first and foremost managers of the company must understand the philosophy of the Lean system.

Only with the full understanding of this philosophy and with the understanding leaders can give of innovations-based instructions for employees.

4.2. Adapting the Outsourcing System to Transport Activities

Almost every Lithuanian company uses the services offered by various companies to facilitate their work and reduce costs. Outsourcing allows business management to save more time. It is better to transfer some activities to others than don't having some skills to try to do it or hire a high-cost employee. Outsourcing enables companies to transfer part of their business to other hands in order to be more effective.

Outsourcing enables the company to save money and allocate funds to other areas of its business. Outsourcing is not targeted at employees, so outsourcing is a good way to find suitable and qualified employees for your business. Rent other companies provided services are worthwhile when the company seeks to reduce and control operating costs. Rental of services helps companies save money and allows them to use them in more important areas of the company's business. Outsourcing helps the company focus on the company's core business and ignores other areas of secondary activity. To free up existing resources to achieve other goals, a decision can also be made to take advantage of the outsourcing services. A transport company may want to lease services in order to make a certain work more qualitative and cheap, as this is the only case where the quality of service is high and its costs are lower. In this way, the company's work process is being improved, as some work is done by the team of the best specialists.

Outsourcing has many advantages. It enables organizations to take advantage of what is best, most professional in the relevant field. Outsourcing reduces risk and, in most cases, helps save money. Another great benefit is that outsourcing helps organizations avoid bottlenecks. Because, it is taken care of professionals who are specializing in the relevant field. However, there are hardly any benefits to them. Outsourcing also has problematic areas. The statistics show that 20–25 percent relationships based on outsourcing (both in terms of production and services) are interrupted in the first two years, and another half in five years. Such figures are an outsourcing problem. The literature states that they are caused by reasons such as insufficient supplier competence, high price, poor service, lack of cooperation, etc. While outsourcing has a long list of advantages, it is worth mentioning its disadvantages. First, no one is protected from the unreliable suppliers. Suppliers can provide false information about themselves and in other ways to persuade to another outsourcing part about their unjustified skills.

5. Conclusions

To summarize the analysis of literature, one can be stated, that business risk is not limited to accidents, technological errors or insufficient commercial or management experience.

It has been noticed that business risk is mainly related to the company's finances, the management's inability to reconcile operating and production costs with incomes.

After undertaking analysis of companies' risk, it turned out, that the biggest threats to transport companies are: labor shortage and increased prices of raw materials. According to the research results it can be argued that for transport risk management is now given more attention than 10 years ago. According to respondents, this was influenced by: insurance, renewal of parks, cargo specifics.

According to respondents, the main resources and focus should be on internal and external environmental analysis and risk identification. In their opinion, the external factors that have the biggest impact are economic downturn, market shrinkage, internal factors – carriers' mistakes, and delays in payments.

The logistics (supply) manager should be responsible for the management of transport risk in the enterprises.

Risk reduction should be addressed through prevention and disposal. It would be best for transport companies to carry out risk prevention, with prior assessment of potential threats.

One of the ways to reduce the risk is to apply the Lean system and adapt the Outsourcing system to the transport company.

Lean's strategy is a fundamental change of direction, which involves a certain problem and at the same time with a certain risk.

Outsourcing reduces risk and allows transport companies to take advantage of what is most professional in the relevant field. Thanks to Outsourcing, a company can save money and allocate funds to other areas of its business.

References

1. **Aleknavičienė, V**. 2005. Finansai ir kreditas. Vilnius: Enciklopedija.
2. **Ališauskas, K.; Kazlauskienė, Ž.** 2005. Investicinių projektų rengimas, valdymas ir vertinimas. Šiauliai: Šiaulių universiteto leidykla.
3. **Anderson, E.W.; Chysels, E.; Juergens, J.L.** 2009. The impact of risk and uncertainty on expected Returns, Journal of Financial Economics 94: 233–263.
4. **Balžeikienė, A.** 2009. Rizikos suvokimas: sociologinė konceptualizacija ir visuomenės nuomonės tyrimo metodologinės prielaidos, Filosofija. Sociologija 20(4): 217–226.
5. **Batarlienė, N.** 2008. Risk analysis and assessment for transportation of. Dangerous freight, Journal Transport 23(2): 98-103.
6. **Batarlienė, N.; Čižiūnienė, K.; Vaičiūtė, K.; Šapalaitė, I.; Jarašūnienė, A.** 2017. The impact of human resource management on the competetitiveness on transport companies; Procedia Engineering. Transbaltica 2017. ISSN 1877-7058, 18: 110-116.
7. **Beasley, M.S.; Clune, R.; Hermanson, D.R.** 2005. Enterprise risk management: An empirical analysis of factors associated with the extent of implementation; Journal of Accounting and Public Policy 24(60): 521–531.
8. **Būda, V.; Chmieliauskas, A.** 2006. Projektų valdymas. Kaunas: Technologija.
9. **Duxbury, D.; Summers, B.** 2004. Financial risk perception: Are individuals variance averse or loss averse? Economics Letters 84(1): 21–28.
10. **Jarašūnienė, A.; Jokūbaitis, D.** 2017. Bankroto specifika transporto ir logistikos sektoriuje, Proceedings of the 20th conference for junior researches "Science – Future of Lithuania". Vilnius VGTU. 163-166.
11. **Jordan, A.** 2013. Risk Management for Project Driven: Organizations A Strategic Guide to Portfolio, Program and PMO Success. J. Ross Publishing, Canada. ISBN: 978-1-60427-085-3.
12. **French, S.; Liang, Y.** 1993. Decision support systems: a decision analytical perspective, in Norman, J. (Ed.). Developments in Operational Research. Birmingham: Operational Research Society.
13. **Garškienė, A.** 1997. Verslo planavimas. Vilnius: Lietuvos informacijos institutas.
14. **Gronskas, V.** 2003. Rizika mišrioje ekonomikoje: samprata ir sandarac, Inžinerinė ekonomika 3(34): 46–53.
15. **Laskienė, D.; Snieška, V.** 2003. Verslo rizikos samprata ir struktūra. Inžinerinė ekonomika. 3: 55–60.
16. **Makštutis, A.** 2008. Harmonious Development of Lithuanian Economy and Market Today. Theory and practice. In: International Conference: Evolution in the Global Knowledge Economy: Enhancing Innovation and Competitiveness Worldwide. Madrid, pp. 23–34.
17. **Nedzveckas, J.; Rasimavičius, G.** 2000. Faktoriniai modeliai ir vertybinių popierių pajamingumas, Inžinerinė ekonomika: mokslo darbai. 1: 18–22.
18. **Rejda, G.E.** 2008. Principles of Risk Management and Insurance. 10th Edition. Boston: Pearson.
19. **Smithson, Ch.; Simkins, B.J.** 2005. Does risk management add value? A survey of the evidence, Journal of Applied Corporate Finance 17(3): 8–17.
20. **Stankevičius, R.** 2005. Rizikos samprata ir jos valdymas muitinėje (Risk Conception and its Assessment in Customs), Jurisprudencija, t. 69(61): 70-76.
21. **Startienė, G.** 2002. Tarptautinės prekybos finansavimas: rizika, mokėjimai, kreditavimas. Vadovėlis. Kauno technologijos universitetas.
22. **Van Brunschot, E.G.** 2009. Gambling and Risk Behaviour: a Literature Review. The Alberta Gaming Research Institute. Available from Internet: https://dspace.ucalgary.ca/ bitstream/1880/47229/1/Gambling_and_Risk_ Behaviour_Literature_Review_March_2009.pdf

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Impact of Line Electrification on Operation of Railways

A. Massel

Railway Research Institute, Chlopickiego 50, 04-275 Warszawa, Poland, E-mail: amassel@ikolej.pl

Abstract

After several years of stagnation, the realization of line electrification projects has been undertaken again in Poland. Similar processes can be observed in numerous European countries, for example in Denmark, Germany, Great Britain, Lithuania, Belarus. Particular attention is paid to bridging gaps and to creating missing links in electrification.
Traditionally the decisions on electrification of particular sections of the railway network were usually based on economic factors. In 1970s and 1980s so called electrification thresholds were used in Poland to justify the need for electrification of particular railway line. They took into the number of tracks (single-track lines, double-track lines), terrain conditions (flat terrain, upland terrain) and the traffic structure (the share of passenger traffic) into account.
Also today electrification of railway lines all over the world is undertaken mainly due to economic reasons. Usually electric trains are cheaper, more reliable and longer-lasting than equivalent diesel ones. They also have better acceleration and journey times can be shorter, even with relatively frequent stops.
In XXI century the importance of environmental aspects grows. In several countries there are plans and the aim should be to eliminate diesel operation and create an ultra-low emission, zero-carbon, high technology railway.
The paper deals the role of operational criteria in the decision-making process concerning electrification of railway lines. These criteria include the benefits for passengers, in particular shortening of the journey times on particular sections, shortening of stops on the stations with the change of the type of traction. However they should also tackle the savings of train operating companies resulting from the traction unification (change of demand for rolling stock and for workshops for its servicing), improvement of reliability and punctuality of services.
KEY WORDS: *electrification, operation, traction, railway, criteria.*

1. Introduction

Electrification of the Polish mainline railways started in the years 1936-1937 with the wiring of three line sections in the Warsaw Railway Node. 3000 V direct current system was then selected for the Polish network. The process of electrification was continued, although with changing intensity, till early 1990s. The largest growth rate has been observed in late 1980s. The total length of railway lines electrified between 1986 and 1990 has achieved 2485 km, i.e. 497 km per year. The latest large electrification projects in Poland were finalized in 1994 and covered Klodzko – Miedzylesie (36 km) and Olsztyn – Elblag (99 km) sections. Further electrifications covered very short sections (usually newly built connections in agglomerations, for example airport links).

Despite the political constraints of the times after World War II, the decisions on electrification of particular sections of the railway network were usually based on economic factors. Typically the economic evaluation was performed for one or a few representative sections characterised with typical traffic structure and average line profile, average distances between stops, average train weights and train speeds.

The European railways have recently been significantly transformed through implementation of the EU legislation imposing “unbundling”, i.e. strict separation of infrastructure management and operation of passenger and freight services. Consequently, the approach for railway infrastructure investment appraisal has also been changed. It is also the case of electrification schemes. Relevant costs and benefits of such investment have to be allocated to particular stakeholders: infrastructure managers, train operating companies, competent authorities responsible for contracting public services.

The paper deals with the justification of electrification projects from the point of view of train operating companies (rail operators).

2. Existing Works on Effectiveness of Railway line Electrification

The effectiveness of switching from diesel to electric traction has been discussed in several publications. Some of them were dedicated to methods for analysis of costs and benefits of changing type of traction. First of all it is necessary to mention the Polish works from 1970s and 1980s, in which analyses were based on (so called) electrification thresholds, which were used to justify the need for electrification of railway line in question. They took into the number of tracks (single-track lines, double-track lines), terrain conditions (flat terrain, upland terrain) and the traffic structure (the share of passenger traffic) into account. These thresholds were used not only for analysis of the particular case of the railway line but also to establish the order, in which particular railway lines should be electrified and to define the rational scope of electrification of the national railway network [8],[9]. The above mentioned method

has been elaborated in COBiRTK (Central Unit for Railway Research & Development), predecessor of Instytut Kolejnictwa (Railway Research Institute). It is noteworthy, that a bit similar approach can be also found in recent Hungarian publications by Csaradi [2, 3].

Representative example of cost-benefit analysis for railway electrification is presented in the paper by Al-Tony et al., in which the economic and financial viability of a proposed electrification scheme for the Cairo–Alexandria railway line is being examined [1]. The framework of appraisal developed identifies the potential direct and indirect benefits of the scheme, and its costs.

Various aspects of railroad productivity that might be influenced by the adoption of electrified operation of railways were evaluated by Ditmeyer et al. Productivity was considered from the viewpoint of motive power, transportation economics, signaling and train control, and railway operations [4].

In the paper by Tomczyk et al., the research team from Gdansk University of Technology proposed complex model for calculating economical threshold for railway line electrification taking the factors regarding constant and variable cost, such as a dynamics of the train or energy prices into account [10].

Usually electric trains are cheaper, more reliable and longer-lasting than equivalent diesel ones. They also have better acceleration and journey times can be shorter, even with relatively frequent stops. The real difference between electric rolling stock and its alternatives strongly depend on local conditions of the country, region and particular railway line. For example according to Network Rail (the rail infrastructure manager in the United Kingdom) the electric trains are cheaper than diesel ones because [15]:

- they are cheaper to build and 20% cheaper to lease;
- maintenance costs are typically 33% lower;
- fuel costs are typically 45% lower because electric trains are lighter and more efficient and electricity from the National Grid is cheaper than diesel fuel;
- electric trains are lighter and therefore cause on average 13% less wear to the tracks;
- track maintenance costs are therefore lower.

The selection of type of traction usually have also impact on service quality. Electric trains can be more comfortable because they are quieter and vibrate less due to the absence of diesel engines. Moreover they typically [15]:

- they have a higher power-to-weight ratio, which means that they are generally faster than diesel ones;
- they accelerate more quickly, which reduces the journey times.

Areas with limited clearance, such as tunnels and sections through overbridges, are particularly expensive to electrify. In paper by Hoffrichter et all [6], train performance on the Great Western Main Line (GWML), from London Paddington to Cardiff and vice versa, is modelled for three cases:

- no electrification;
- full electrification; and
- electrification that does not include tunnels, most notably the Severn Tunnel.

The paper by Kirkwood et al deals with the typical problems Overhead Line Equipment projects face, when analyzing the best option for overbridges. The three competing options (bridge rebuild, track lowering, reduced clearance) have very different capital expenditure (CAPEX) and operating expenditure (OPEX) costs. A model was elaborated to predict these costs over the anticipated assessment period [7].

In the study of rail freight electrification for Southern California, the three key electrification technologies have been analysed: straight-electric (with catenary on the entire line); dual-mode (with catenary on some sections); and a linear synchronous motor (LSM) system. All above mentioned technology alternatives and each geographic option within each alternative have been evaluated based on technology readiness, railroad operations impacts, total capital cost, energy cost savings and total emissions reduction in the region [13].

In XXI century the importance of environmental aspects grows. In several countries there are plans and the aim should be to eliminate diesel operation and create an ultra-low emission, zero-carbon, high technology railway. Therefore in several cases it is necessary to consider electrification of railways with low or moderate traffic. Comprehensive analysis of solutions alternative to overhead line electrification in the conditions of Norwegian railways can be found in the report of SINTEF [11]. The study was carried out in collaboration with JBV (Norwegian Railway Administration). It covered two phases. The first phase was mainly a methodological one and included selection of evaluation criteria, weighting, assumptions and was finished with screening. The second phase covered detailed assessment for identification of future solutions for rail propulsion. Several possible alternatives have been considered: biofuels, natural gas, hydrogen, batteries, diesel, overhead lines, hybrids. They have been evaluated according to the following criteria: economy, flexibility and robustness, technology readiness, regulatory framework, environment. The detail assessment have been conducted for the Nordland line section between Steinkjer and Bodo. This is the single track line, more than 600 km long, crossing the polar circle, with rather limited passenger and freight traffic. In total there are 3000 train movements per year (around 8 trains per day). The analysis for freight traffic has shown, that hydrogen solution was the cheapest, while battery option was very close second [11].

The existing publications on electrification of railways are usually focused on its technical aspects or on its costs and benefits. They are, however typically restricted to the analysis of the single line in question (to electrify or not to electrify?). There is a lack of works considering the operational aspects of electrification, especially in a network scale.

3. European Experience

It should be noted, that more than the half of the railway lines in Europe have already been electrified. In 2015 the total length of electrified lines in use in all European Union member states exceeded 116 thousand kilometres. The electrified EU rail network is still developing. In 2007-2015 period it increased by more than 5 thousand kilometres. The mean annual growth rate at that time equalled to 633 kilometres. The largest increase of length of electrified lines has been observed in case of Spain (1112 km), France (843 km), Germany (802 km) and Italy (405 km). However, at least in case of Spain and France, that growth can be attributed mainly to the construction of new high-speed lines. All these lines have been built as electrified ones.

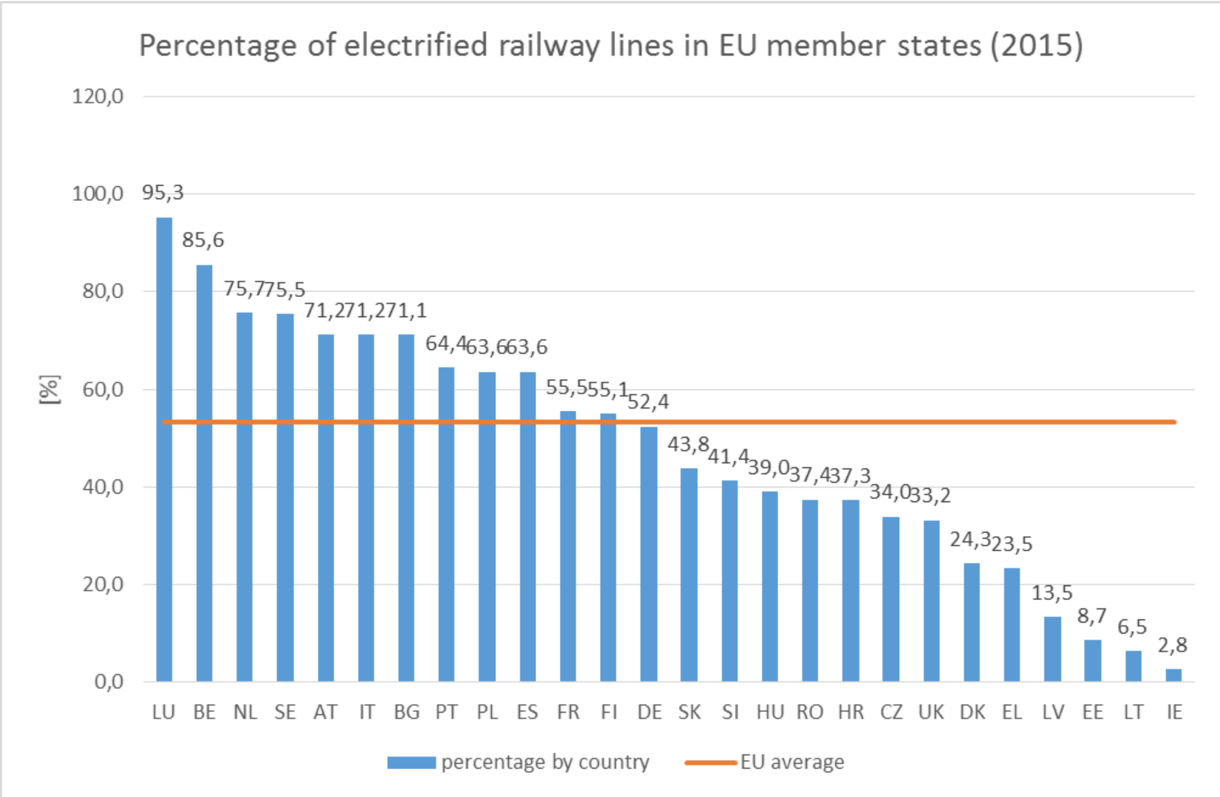


Fig. 1 The railway electrification ratio for EU member states [14]

In 2015 the average share of electrified lines (electrification ratio) in the entire EU network achieved 53.2% [14]. The leading countries are Luxemburg (95.3%), Belgium (85.6%) and the Netherlands (75.7%). There are several countries, however, in which the scope of electrification has been restricted to the suburban networks serving agglomerations around capital cities: Ireland (2.8%), Lithuania (6.5%), Estonia (8.7%) and Latvia (13.4%). There is a diversity of electrification projects in Europe. Their objectives and scopes largely depend on the local conditions.

In countries with small or moderate share of electrified lines, the on-going electrification projects usually concern main lines, with significant share in the total passenger and freight traffic. Representative example is the case of Lithuanian railway network. Till the year 2017 only 122 km of railway lines were electrified. Taking into account the total length of the network – 1877 km, the share of electrified lines at that time was about 6.5%. Moreover, the existing electrification has been utilised by passenger trains only. The freight traffic, including the entire East-West railway corridor, from Belarus border to Klaipeda, has been handled with diesel traction. Lithuania, however, intends to electrify this corridor. Between 2015 and 2017 the first phase of the project was carried. It envisaged the electrification of a 28.6 km linking Kena on the border to Naujoji Vilnia [16]. As the next stage of the project it is planned to electrify Vilnius railway junction – 34 km of Vilnius bypass – by connecting it to the already electrified Vilnius – Kaunas section. Two following stages of planned electrification are Kaisiadorys – Radviliskis section of 125 km and Radviliskis – Klaipeda section of 196 km [16]. Fulfilment of these planned investments, co-financed from EU Cohesion Fund, should result in the increase of the electrification ratio to approximately 27% in the year 2023.

In countries with larger share of electrified lines the present electrification projects in some cases concern the main lines with moderate traffic, but also secondary lines. Very good examples of recent electrification projects can be found on a German railway network. The present electrification ratio for Germany, 52.4%, is considered as inadequate. In Spring 2018 the works started on about 155 km long section between Geltendorf and Lindau via Buchloe – Memmingen. This investment should be finished till the end of the year 2020. It is intended to bridge the gap in electrification of the international link between Munich and Zurich and to avoid the change of traction from diesel to electric (and vice versa) on Lindau station. The objective is to reverse the situation where existing EuroCity services on

that route are no longer competitive/ A trip by one of just four daily trains each way today takes around 4 h 15 min, but 16 coaches a day using motorways cover the same journey in 3 h 45 min or little more. A driver in a private car can complete the trip in 3 h 15 min [17]. The electrification, together with the implementation of high-speed electric motor units of Swiss Federal Railways (SBB), should shorten the journey time on this route to approximately 3 h 25 min (by around 50 minutes).

Similar electrification project has also been started on the main line between Ulm, Friedrichshafen and Lindau (128 km). It should be finished by 2021. On the other hand the electrification of several secondary lines has been undertaken recently, especially in Baden-Würtemberg (Freiburg – Breisach, Neustadt – Donaueschingen).

4. Operational Aspects of Electrification

From operational point of view very important factor seems to be the flexibility of rolling stock utilisation. Therefore every point of the network, at which changeover from electric traction to diesel traction (or vice versa) takes place, forms significant problem for railway operators due to need for change of the locomotive (in case of passenger and freight trains), or need for change of the train (in case of passenger trains only).

Rolling stock is usually the most expensive asset of train operating company. Every change of rolling stock (electric locomotive versus diesel locomotive, EMU versus DMU) usually generates additional cost for the train operating company, due to need for dedicated infrastructure (workshops) for servicing both kinds of traction and for personal at these locations.

Fig. 2 Change of the locomotive at the express train Warsaw – Hel in Gdynia station

The change of locomotive from electric to diesel one (or vice versa) imposes extended stopping time at involved station. Typical time for change of the locomotive (in case of the passenger train) was traditionally around 8-10 minutes. However in case of the new generation of locomotives this time can be extended up to 20 minutes or even more, due to the need for turning off the diesel engine, switching off all on-board computer systems, protecting against electric shock, etc. (Fig. 2). Representative examples from various locations in Europe are presented in Table.

Table

Loco change times for long-distance trains

Country	Station	Trains involved	No of trains [pairs per day]	Time for change [min]	Remarks
Croatia	Ogulin	Zagreb - Split	2	9-34	Reversal of the train
Czech Rep.	Plzen	Muenchen - Prague	7	11-12	
Germany	Regensburg	Muenchen – Hof/Prague	11	8-12	Reversal of the train
Finland	Oulu	Helsinki – Kolari	1	30-34	Oulu – Kemi under wires
Hungary	Miskolc-Tiszai	Budapest – Satoraljauhely	5	12-13	Miszkolc – Szerencs under wires
Hungary	Puspokladany	Budapest – Cluj/Brasov	3	16-28	
Poland	Lukow	Warsaw - Lublin	8	18-27	
Romania	Brasov	Bucharest – Sibiu (-Budapest – Vienna)	4	12-18	
Slovakia	Zvolen	Bratislava - Kosice	4-5	13-17	

Another possibility at traction change location is to arrange connection from electric train (operated with EMU) to the diesel one (DMU). In that case some time (usually a few minutes, depending on the layout of the platforms on the station) is necessary for passengers to move from one train to another one. Apart from wasting of time, such change can

form inconvenience for passengers, particularly for elderly people, as well as for passengers with reduced mobility (PRM).

As an alternative for electrification, if travel times are very important, more expensive locomotives with dual mode engines can be used. However from operational point of view, the most practical solution would be uniform traction on entire network (100% of electric traction, 100% of diesel traction). Time losses related to the change of traction can be accepted only in cases of routes with very small traffic. Therefore it is quite understandable, that in several cases a main reason for electrification of particular section is compatibility of the network. When electrifying a line, the connections with other railway lines should be considered. It is noteworthy, that those connections are particularly important in case of traffic disruptions on railway lines and they allow for diverting trains to alternative routes without need for other traction unit.

The good example for importance of alternative electrified routes was the traffic breakdown on the Karlsruhe - Basel main line in southwest Germany, one of Europe's key rail freight arteries forming critical part of the Rhine-Alpine corridor (Rotterdam – Genova) in the year 2017. The line had to be closed from August 12 till October 2 following a major earth movement caused by groundwater entering the construction site of the new tunnel being built under Rastatt [19]. The double-track section between Rastatt and Baden Baden is already a major bottleneck on this very busy main line, which is used by up to 200 freight trains a day plus over 100 regional and international passenger services.

Due to lack of alternative electrified route, huge disruption occurred. For the duration of the interruption, which is partly due to the holiday period, 162 freight trains were expected to leave on a daily basis, meaning that 8,262 freight trains could have been operated under normal conditions. In fact, only 33% of "scheduled" freight trains operated during the interruption, but partly under unfavourable operational conditions. 67% of the freight trains were cancelled [19]. The passenger trains (including long-distance trains) had to be substituted with buses.

5. The Need for Operational Criteria

Traditionally the effectiveness of the infrastructure investment is being assessed through the economic analysis. The principles for such analysis are presented in various publications, for example by Dyr et al [5]. However in assessing the need for electrification of particular line segment it seems absolutely necessary to cover essential operational factors in CBA analysis. The following factors can be taken into account:

- the number of trains operated on the segment;
- the number of trains running through from (or to) electrified part of the network;
- the passenger flows on the segment;
- the number of transfer connections from (or to) electrified part of the network;
- the typical time necessary for changing locomotive from electric to diesel one;
- the average time for passenger to change from diesel-operated train to the electric one (and v.v.);
- journey time difference (diesel traction versus electric traction) for all types of trains operated on the line segment and for all stopping patterns);
- existence of alternative routes (electrified, not-electrified).

The electrification brings several benefits for passengers, especially due to reduction of stops at the stations with change of traction and due to shortening of journey times thanks to better traction characteristics of electric locomotives (in comparison to diesel ones) and of EMUs (in comparison to DMUs). The scale of benefits for passengers can be illustrated with the following example. Let us assume, that the traction change is necessary on given long-distance route. The characteristics of the service is as follows:

- number of trains pairs per day: 8;
- Average number of passengers per train: 200;
- structure of motivation of journey: 20% duty journeys, 20% journeys to/from work, 60% other reasons;
- stopping time for change of the locomotive (diesel-electric, electric-diesel): 20 minutes;
- stopping time necessary for passengers: 2 minutes;
- running time difference (electric vs. diesel): 10 minutes.

The real journey time difference in this particular case is around 28 minutes (10 minutes as a result of faster running plus 20 minutes thanks to elimination of technical stop for loco change minus 2 minutes for passenger). It should be remembered that economic benefits resulting from shortening of the train journey are strongly dependent on unit Values of Time (VOT). The Value of (travel) Time denotes the exchange rate at which a traveller is indifferent to marginal changes in the time and cost involved in travel [18]. According to Jaspers Blue Book for Public Transport project appraisal the VOT values (per hour) for Poland for the year 2018 are as follows [12]:

- 16.04 EUR (69.78 PLN) for duty journeys;
- 7.90 EUR (34.38 PLN) for journeys to or from work;
- 6.63 EUR (28.85 PLN) for other journeys.

Taking into account these values, estimated benefit resulting **only** from shortening of the journey for analysed train service is around 3.33 million EUR per year.

The savings of train operating companies resulting from the traction unification are:

- the change of demand for rolling stock, due its better utilisation (more trainkilometres per vehicle);

- the change of demand for workshops for rolling stock servicing;
- the change of demand for train personnel.

Thank to elimination of the loco changes less locomotives is usually necessary to haul the trains on involved non-electrified section. For example if the diesel locomotive can make 400 km a day, while the electric locomotive in case of through working – 600 km day, it means that 10 electric locos can replace 15 diesel ones. Another benefit (for passengers and for train operators) is the improvement of reliability and punctuality of services.

6. Conclusions

The importance of electrification of railways has grown recently. After long time of stagnation, numerous electrification projects have recently been undertaken in several countries in Europe and overseas. In the meantime the railway environment has significantly been changed. According to the EU directive, the railway undertakings have been separated from infrastructure managers. The needs of the train operating companies must be taken into account at the stage of planning of railway investment. It is necessary to enhance methods of economic assessment of railway electrification projects. CBA analyses should not be restricted to short sections in question only. They should rather take costs and benefits of operators, resulting from switching to electric traction on larger area (entire regions) into account.

References

1. **Al-Tony, F.; Lashine, A.** 2000. Cost-benefit analysis of railway electrification: case study for Cairo-Alexandria railway line, Impact Assessment and Project Appraisal,18(4): 323-333.
2. **Csaradi J.** 2017. Vasut villamositas gazdasagosan (Railway Electrification, Economically). Vasutgazdasag 2. , p. 26-30 (in Hungarian).
3. **Csaradi J.** 2017. Vasut villamositas gazdasagosan (2. resz) (Railway Electrification, Economically, part 2). Vasutgazdasag 3. , p. 12-16 (in Hungarian).
4. **Ditmeyer, S; J. Martin, J.; Olson, P.; Rister, M.; Ross, B.; Schmidt, J.; Sjokvist, E.** 1985. Railway electrification and productivity: A Study report. Transportation Research Record 1029: 23-30.
5. **Dyr, T.; Kazubek, P.** 2011. Assessment of transport infrastructure investment co-financed from EU funds .Spatium, Radom (in Polish).
6. **Hoffrichter, A.; Silmon, J.; Schmid, F.; Hillmansen, S.; Roberts, C.** 2013. Feasibility of discontinuous electrification on the Great Western Main Line determined by train simulation. Proceedings of the Institution of Mechanical Engineers Part F – Journal of Rail and Rapid Transit. 227, Issue: F3, 296 p.
7. **Kirkwood, I.; Giuntini, L.; Shebab, E.; Baguley, P.** 2016. Development of a Whole Life Cycle cost model for electrification options on the UK rail system. Elsevier. Procedia CIRP, 47, 1-5.
8. **Kuczborski, S.; Polak, Z.; Wasilewicz, W.** 1974. Kryteria kolejności elektryfikowania linii kolejowych (Criteria for the order of electrification of railway lines). Przegląd Komunikacyjny, 5, p. 3-11 (in Polish).
9. **Kożuchowski, K.; Polak, Z.; Wasilewicz, W.** 1980. Niezbędny zakres elektryfikacji kolei w aktualnej sytuacji paliwowo-energetycznej (Necessary scope of railway electrification in the current situation in fuel and power supply). Przegląd Komunikacyny, 1, p.8-16 (in Polish).
10. **Tomczyk, M.; Pacholski, M.; Karwowski, K.** 2016. Comprehensive modelling of the cost effectiveness of railway line electrification. Zeszyty Naukowe Wydziału Elektrotechniki i Automatyki PG, 51, p. 197-200.
11. Analyse av alternative driftsformer for ikke-eletrifiserte baner. 2015. SINTEF, Report A 27534 (in Norwegian).
12. Blue Book. Public Transport Sector in cities, agglomerations and regions. 2015. Jaspers (in Polish).
13. Comprehensive Regional Goods Movement Plan and Implementation Strategy. 2012. Task 8.3: Analysis of Freight Rail Electrification in the SCAG Region. Southern California Association of Governments, (Cambridge Systematics).
14. EU Transport in figures – Statistical pocketbook 2017. Luxembourg: Publications Office of the European Union, 2017, 80 p.
15. Network Rail. A Guide to Overhead Electrification. 132787-ALB-GUN-EOH-000001. February 2015 Alan Baxter.
16. New electrification works on Lithuanian's East-West corridor. Railway Pro [online cit.: 2018-06-27]. Available from: https://www.railwaypro.com/wp/new-electrification-works-lithuanian-east-west-corridor/
17. Rebuilding business on an inter-regional corridor. 2015. Railway Gazette International, 10, p. 52-55.
18. The Economic Appraisal of Investment Projects at the EIB. 2013. European Investment Bank, p. 79-81.
19. Volkswirtschaftliche Schäden aus dem Rastatt-Unterbruch - Folgenabschätzung für die schienenbasierte Supply-Chain entlang des Rhine-Alpine Corridor 2017. 2018. Hanseatic Transport Consultancy, Hamburg.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Mapping of SSR Transponder Triggering Areas Outside a Radar Operational Coverage

S. Pleninger[1], T. Lipták[2]

[1]*Czech Technical University in Prague, Faculty of Transportation Sciences, Department of Air Transport, Horská 3, 128 03, Prague, Czech Republic, E-mail: pleninger@fd.cvut.cz*
[2]*Czech Technical University in Prague, Faculty of Transportation Sciences, Department of Air Transport, Horská 3, 128 03, Prague, Czech Republic, E-mail: liptatom@fd.cvut.cz*

Abstract

The paper deals with the mapping of an area behind the secondary surveillance radar mode S (SSR Mode S) operational (surveillance) coverage where the power level of interrogations is still above the triggering level of the on-board transponders. The goal was to find out the size of these areas in a real environment and the aspects which can affect their proportions. The method was based on the ground receiving of aircraft replies that contain an identification of the radar by which they were excited. A more detailed statistical description of these areas has significant implication into further activities as far as 1090 MHz RF band pollution alleviation is concerned.
KEY WORDS: *Secondary Surveillance Radar, Mode S, Surveillance Coverage Map, 1030/1090 MHz RF pollution*

1. Introduction

As presented in the previous article [1], as one of the most contributing messages to 1090 MHz RF pollution, the Mode S Downlink Format 11 (DF11) messages were identified. These messages are emitted by an on-board transponder (XPDR) mostly either as spontaneously emitted acquisition squitter or as replies to Mode S-only all call interrogations from SSR Mode S [5]. Transmission of this second kind message category is standardly blocked by SSR after initial aircraft acquisition process [6]. The interrogator locks-out acquired Mode S targets to All Call interrogations. However, as was found and presented in the paper [1], these messages represent the dominant amount of messages in the measurement records. In more detail, these are messages DF11 with non-zero Interrogator Code (IC≠0). As also discussed in previous articles, the main source of these reports are airplanes located in the area behind the surveillance coverage map where Mode S-only all call interrogations have a power level above the XPDR triggering level. The aim of the analysis whose outputs are presented in this article was to evaluate the size of the area where these messages are emitted. The mapping of this area is based on real environment measurement. This knowledge is the basis for modeling RF bandwidth load 1030/1090 MHz, and for further optimizing processes to reduce RF pollution.

2. Basic Aspects Considering the Analysis

The following limitation regarding the used measurement method had to be reflected:

1. Determining the coverage area of ground measurement receivers.

To capture DF11 replies, the ground-based receiver in Prague (Czech Republic) location were used. In this procedure, it is necessary to determine the analytical area with respect to the area of visibility of the given terrestrial receivers. Area of visibility (receiver coverage) has been determined through longer-term traffic surveillance based on Extended Squitter reports. From the captured position information contained in the DF17 messages, the area of coverage, represented by the green line in Figs. 2 and 3, was determined.

2. Compute the area visible by radar.

As explained above, considered DF11 messages are emitted as replies to captured radar interrogations. Therefore, for each analyzed radar, it was necessary to calculate the area of visibility using a digital terrain model. As a Digital Surface Model (DSM), the Digital Elevation Model over Europe (EU-DEM) from the Global Monitoring for Environment and Security (GMES) RDA project was used. The EU-DEM dataset is a realization of the Copernicus programme, managed by the European Commission, DG Enterprise and Industry. The EU-DEM is a 3D raster dataset with elevations captured at 1 arc second postings (2.78E-4 degrees) or about every 30 meters [2]. Because of the reduction in computational complexity our analysis, the digital data was over-rastered to grid size of 1 km. The entire computational process of radar area visibility has been realized in the Matlab software using the Mapping toolbox (see Fig. 1). The radio wave propagation in the atmosphere was modeled as straight lines on a 4/3 radius Earth. This takes into account the curvature of the signal path due to refraction in the atmosphere. (Radio propagation in the atmosphere is commonly treated as straight line propagation on a sphere with 4/3 the radius of the Earth [3].) The radar area visibility boundary was calculated for visible planes flying at 10 000 meters above mean sea level (MSL). This boundary is represented by the magenta line in Fig. 2.

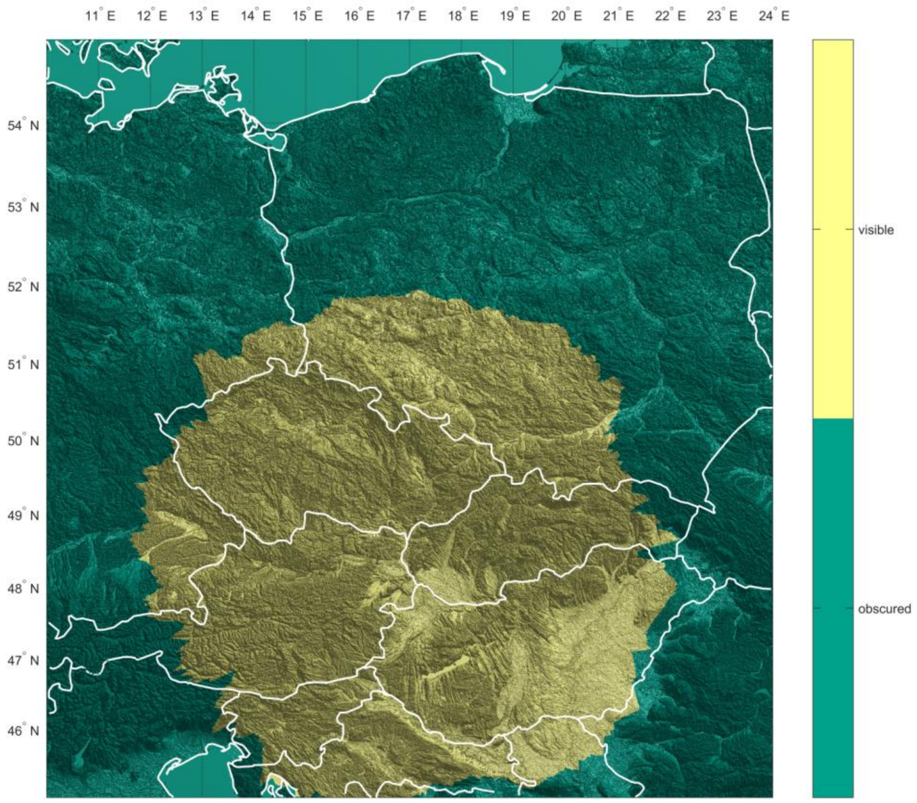


Fig. 1 SSR VIE2 (Austria) radio line-of-sight coverage for 10 000 m height (MSL) based on DEM

3. Association of DF11 messages with a specific SSR.

The basic association of DF11 replies to particular SSR is achieved by means of an Interrogator Code (IC) contained in each DF11 reply that is emitted as a result of receptions of SSR All-Call interrogation. Any two SSR with overlapping surveillance coverage map cannot be assigned the same IC, except when the radars work in the so-called "cluster" [6]. However, our analysis concerns the area behind the surveillance coverage where the aircraft can already be within the physical coverage of two or more radars with the same IC. Physical coverage in this context means the area behind standard surveillance coverage where the interrogations power lever is above the on-board SSR transponder triggering level. In this area the DF11 replies with the same IC may be excited by multiple radars simultaneously. Therefore, it was necessary to analyze the DF 11 message datagram and verify if there was a regular pattern from just one radar.

4. Properties affecting the probability of DF11 messages capture.

The following properties affect the amount of emitted messages and their subsequent probability of successful decoding in the receiver:

A) It is necessary to consider the stochastic acquisition. In UF11 interrogations, the probability parameter can be specified determining the probability with which the reply will be transmitted. We were not able to find out more specific information considering analyzed radars.

B) Transponder occupation time. In the real-world environment, it is necessary to expect that not all transmitted interrogations are successfully received and processed by an on-board transponder.

C) It is necessary to consider the fact that not all the replies are successfully received, decoded by receiver and subsequently present in the output record.

D) The signal level distribution during antenna beam swept is different. Only interrogations at the main lobe maximum will be above the transponder triggering level for aircraft located at the edge of physical coverage.

3. Measurement Results and Discussion

With reference to the above outlined limiting factors, it was possible to obtain relevant results for SSR listed in Table 1. The column labelled as the "DF11 Area Boundary" represents the edge of the area behind the surveillance coverage inside which 90% of all received DF11 messages with particular IC were elicited. This number represents an average boundary within the analyzed area, i.e. within coverage area of our ground receiver represented by green line in Figs. 2 and 3. In detailed analysis it was found that for all radars stated in Table 1. this border corresponds to the radio line-of-sight horizon of the particular SSR. As shown in Figs. 2. and 3., where exact areas are depicted for Velký Javorník (Slovak Republic) and SSR Linz (Austria), the boundary of the DF11 replies excitation area (blue area) corresponds quite exactly to the calculated radio horizon (magenta line).

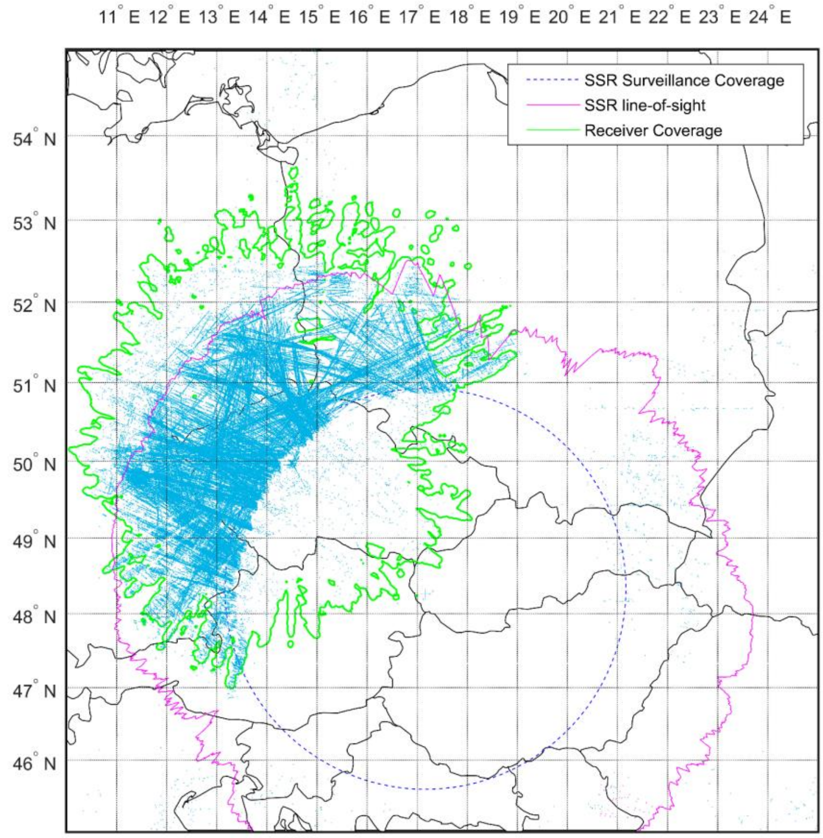


Fig. 2 SSR Velký Javornik (Slovak Republic), SI=28. Surveillance coverage map 160 NM

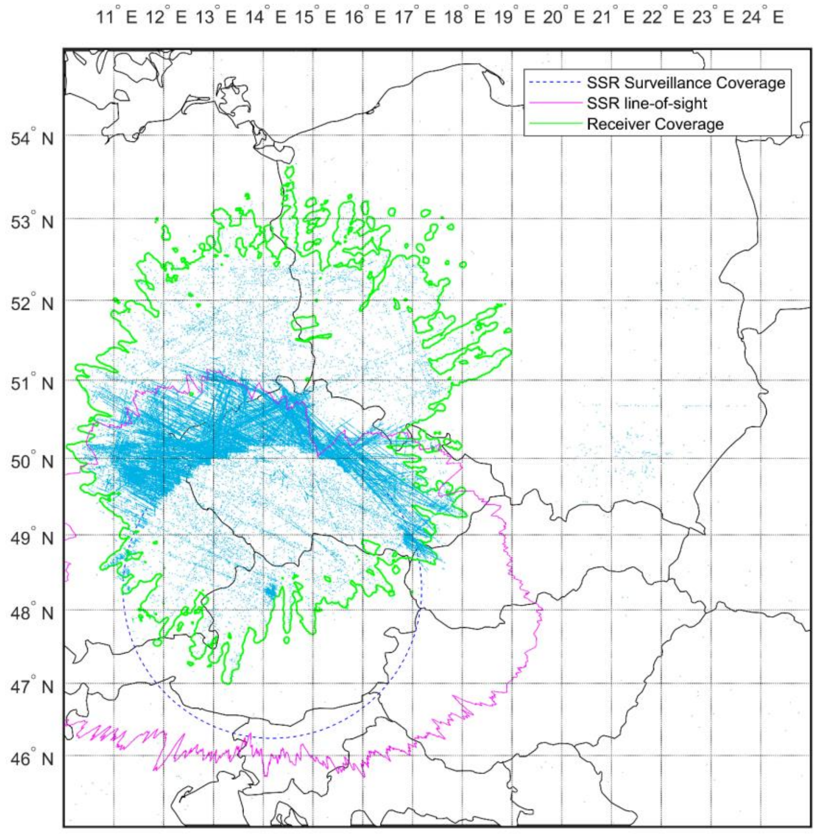


Fig. 3 SSR Linz (Austria), II=8. Surveillance coverage map 120 NM

Table 1

Detailed analyzed SSR Mode S

SSR Mode S Identification	IC	Surveillance Coverage Map [NM]	DF11 Area Boundary (90 % percentile) [NM]	DF 11 Area Boundary Restriction
Ferihegy TAR1	SI=25	150	201	Radio horizon
Kogel	SI=39	180	221	Radio horizon
KOR Austria	SI=53	150	228	Radio horizon
Korishegy	SI=12	200	254	Radio horizon
Linz	II=8	120	160	Radio horizon
Velký Buceň	SI=9	160	209	Radio horizon
Velký Javorník	SI=28	160	232	Radio horizon
VIE2	SI=20	120	208	Radio horizon

4. Conclusions

The aim of the research was to map, based on real-environment measurements, the area beyond the surveillance coverage where DF11 responses are triggered as a result of all-call interrogations from SSR Mode S. The area of measurement (analyzed area) was significantly limited by using only one ground receiver to capture DF11 replies. In spite of this limitation, it was found that for all eight examined radars the boundary determining the furthest area where the DF11 replies are emitted corresponds to the radio horizon of the respective radar. Thus, for SSR with a relatively small operating range, without a significant limitation of the radio horizon, there is a relatively large area in which DF11 replies are excited. These emitted replies have no use in surveillance systems and only significantly contribute to 1090 MHz RF pollution. From the point of view of reducing RF pollution, it is not beneficial to reduce surveillance coverage map because we are losing the ability to apply all-call lockout protocols. If we applied only one interrogation which would set the lockout to all-call interrogations for each 18 s for every airplane in determined area, we would significantly reduce the amount of unnecessary replies. Control information within the interrogation allows the ground sensor to apply lockout which means that the target will not reply to an all-call with that IC for a period of 18 seconds [6].

References

1. **Pleninger, S.; Lipták, T.** 2017. The Issue of Aviation Cooperative Surveillance Systems RF Band Congestion. In: TRANSPORT MEANS 2017 – Proceedings of the international scientific conference. Kaunas: Technical University, 2017. pp. 286-290. ISSN 1822-296X.
2. European Environment Agency (EEA), Digital Elevation Model over Europe (EU-DEM). [online cit.: 2018-05-10] Available from: https://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-original-data
3. MathWorks. Mapping Toolbox™ User's Guide, R2014a. [online cit.: 2018-07-14] Available from: www.mathworks.com
4. ICAO European Principles and Procedures for the Allocation of Secondary Surveillance Radar Mode S Interrogator Code (IC), EUR DOC 024- Edition 1.21. Attachment Mode S interrogator Code (IC) Allocations for the ICAO EUR Region.
5. ICAO Annex 10 to the Convention on International Civil Aviation (Aeronautical Telecommunications), Volume IV, Surveillance Radar and Collision Avoidance Systems.
6. EUROCONTROL, Principles of Mode S Operation and Interrogator Codes, 2003. [online cit.: 2018-06-8] Available from: https://www.eurocontrol.int/sites/default/files/publication/files/surveillance-modes-principles-of-modes-operation-and-interrogator-codes-20030318.pdf

Proceedings of 22th International Conference. Transport Means 2018.

Proposal of Measures to Support in Railway Transport of Steel Billets Between Košice and Linz

L. Černá[1], V. Zitrický[2], A. Dolinayová[3]

[1]*University of Žilina, Univerzitná 1, 010 26, Žilina, Slovak Republic, E-mail: lenka.cerna@fpedas.uniza.sk*
[2]*University of Žilina, Univerzitná 1, 010 26, Žilina, Slovak Republic, E-mail: vladislav.zitricky@fpedas.uniza.sk*
[3]*University of Žilina, Univerzitná 1, 010 26, Žilina, Slovak Republic, E-mail: anna.dolinayova@fpedas.uniza.sk*

Abstract

Railway transport has a significant position in the European Union economics, about 9.000.000 people are employed in this transport sector. Strategy of the European Union, which is oriented on the improvement of economic and social cohesion, better integration between member states and above all in the environmental problematic, railway transport is one of the decisive transport mode. The position of freight railway transport is still not at the desired level in the common transport market, despite the legislative measures adopted. In 2007 liberalisation of railway transport market allowed free competition in railway transport market, but positive trend of transport volume by railway was restrict by the financial crisis, which started in the 2009. Financial crises influenced all transport sectors and its consequences meant decrease of transport performance for all transport modes. After the financial crisis transport market has grow increased again, but railway transport is still under the transport performance before the crisis. Till the year 2015 market share of competing freight carriers' growth approximately doubled. Paper is focused on the proposal of support in railway transport between railway stations Haniska pri Košiciach and Linz Voestalpine. Proposed measurements for support of railway transport will be oriented for optimal selection of transport route. Select criteria for optimization transport processes take into account kind of goods, type of wagons and locomotives, technical specifics of rail infrastructure, which could be used for this selected transport. Paper also contains cost economic analysis for proposed variants of transport. The proposal also reflects transport law and relationships between contractual and executive carrier in European Union.
Key words: *measures, iron gates, transport capacity, optimization, railway transport*

1. Introduction

Mobility of goods is a basic factor of the EU internal market and it creates conditions for the competitiveness of European industry and services. It has a major impact on economic growth and employment. The volume of inland freight transport in the EU (including road, rail and inland waterway) is stabilized at around 2 300 billion tonne-kilometres per year in last years and road transport has 75% share on the transport market in EU. However, transport also has a negative impact on the environment and the quality of life of EU citizens and it accounts for about one-third of the EU's energy consumption and total CO2 emissions. One way how to reduce negative influences of transport on the environment is using the environmental friendly transport mode –railway and inland waterway transport. According to the European Environment Agency, CO2 emissions in railway transport are 3.5 times lower per tone-kilometer than in road transport emissions. Sustainable transport modes could also help reduce the cost of road congestion, which, according to current estimates, is expected to increase by 50% by 2050 to almost 200 billion. EUR per year and reduce the number of traffic accidents [1-5].

The aim of the paper is proposal the mode of transportation of steel billets in the international transport route between Košice and Linz, specifically between railways stations Haniska pri Košiciach and Linz Voestalpine. Mode of transportation will be proposed for optimized costs for carrier.

2. The Current Situation in Transportation of Iron Gates

According to the Harmonised Commodity Code steel billets are classified to the category (76012020) – Unprocessed (raw) aluminium: Aluminium alloys: steel billets and bars. Steel billets are a product of steel company in Košice, they are hot rolled and are manufactured using modern steel techniques. Length of transported steel billets is from 8 to 10 meters, width is till 2 meters and weight is from 12 tons to 36 tons. Steel billets are produced in different variants according of the customer requests.

Current transportation of steel billets is realized by three alternative transport routes in Slovakia:

1. Haniska pri Košiciach – Žilina – Bratislava Petržalka.
2. Haniska pri Košiciach – Zvolen – Bratislava Petržalka.
3. Haniska pri Košiciach – Čaňa/Hidasnémeti – Szob/Štúrovo – Bratislava, (this alternative route is going throught the Hungary).

On the Fig. 1 are steel billets in the form of belts loaded on different type of rail wagons (Res and Eas). Steel billets are loading on the railway siding of steel company in Haniska pri Košiciach.

Source: (Kurtík, 2018)

Fig. 1 Steel billets loaded in the rail wagons

Steel billets mainly are loading to rail wagon Eas. Owner of these wagons is national railway undertaking of Slovakia – ZSSK Cargo. ZSSK Cargo also realizes transportation of steel billets from sending station (Haniska pri Košiciach) to cross-border station Bratislava Petržalka. Private rail operator realizes transportation of steel billets from Bratislava Petržalka to delivery station Linz Voestalpine.

From the analysis in 2017, it was found that steel billets transports are predominantly regular, occasional irregularities are dependent on the order of the customer. Trains to the Linz Voestalpine have maximum norms of weight 2000 t and length norms of 560 m. On the transport route are used different types of locomotives. Between Haniska pri Košiciach and Žilina is used double-locomotive type 131, between Žilina – Bratislava is used locomotive type 363 and from Bratislava to Linz, on Austrian infrastructure, is used locomotive type 383. On alternatives routes rail operators use diesel locomotive type 756.

Unloading place of steel billets is railway siding Voestalpine, steel company in Linz uses steel billets for production of metal sheet.

Transport volume analysis of steel billets

Transport volume analysis was realized in the year 2017, data were analyzed by the months. In analysis were monitored operation indicators of railway transport as well: net weight of transported goods, gross ton kilometer, number of trains and etc.

Table 1

Transport volume analysis of steel billets in year 2007

Month	Number of trains	Net weight of goods (t)
January	3	3,590
February	13	18,241
March	3	4,109
April	14	19,039
May	20	27,703
June	27	36,647
July	22	30,103
August	22	29,267
September	15	20,617
October	21	28,840
November	19	26,178
December	5	6,835

Source: (Kurtík, 2018)

In the Table 1 we can see that the most trains were transported in September (27 trains) and at the least was in January and March (3 trains). Monthly average number of trains was 16 trains by month in the year 2017. Annual transported net weight is 251, 169 t, in average monthly net weight is 20, 93.75 t, it is 8, 33% share from the total weight.

3. The Proposal of an Optimal Transportation of Steel Billets

Transportation of steel billets from Haniska pri Kosšiciach to Linz Voestalpine is possible realized by three routes, cross the Slovak infrastructure (ŽSR), Hungarian infrastructure (MAV) and Austrian infrastructure (OBB), specifically:

1. route Haniska pri Košiciach – Linz VoestAlpine AT via Žilina by the infrastructure ŽSR;
2. route Haniska pri Košiciach – Linz VoestAlpine AT via Zvolen by the infrastructure ŽSR;
3. route Haniska pri Košiciach – Linz VoestAlpine AT via Hungary by the infrastructure MAV.

Next part of paper includes assessment of variants of steel billets transportation according by the parameters: costs of carrier, transport characteristics, fees for the use of rail infrastructure, number of locomotives, technical possibilities of rail infrastructure and etc.

3.1. Cost Calculation for Variants

According on the transportation process total costs of transportation was calculated only on the Slovak infrastructure and it was assessed only transport route, that realized national Slovak rail undertaking – ZSSK Cargo. The total cost in all three variants was calculated for a train with an average number of wagons per month - 27 wagons type Eas. The modelling rates are tailored to the needs of the carrier's business secrets. In the Table 2 are the auxiliary indicators needed to calculate the total costs for each solution variant.

Table 2

Auxiliary indicators for calculation

Variant no. 1		Variant no. 2		Variant no. 3	
Type of locomotive	131	Type of locomotive	756	Type of locomotive	363
Weight of locomotive (t)	169	Weight of locomotive (t)	72	Weight of locomotive (t)	87
Average number of wagons	27	Rate for wagon/day (€)	16	rate for wagon/day (€)	16
Rate for wagon/day (€)	16	Rate for locokm (€/h)	75,9	rate for locokm (€/h)	39,67
Rate for locokm (€/h)	36,35	Rate for employment/h (€)	16	rate for employment/h (€)	16
Rate for employment/h (€)	16	Weight of wagon (t)	23	Weight of wagon (t)	23
Weight of wagon (t)	23	Diesel consumption (l/1000 gtkm)	12	Energy (kW/h)	18,2
Energy (kW/h)	18,2-18,5	Energy consumption (kw/h)	0,9	Energy consumption (kw/h)	0,15
Energy consumption (kw/h)	0,15	Rate for operation (1 wagon) (€)	15,5	Rate for operation (1 wagon) (€)	15,5
Rate for operation (1 wagon) (€)	15,5	Rate for operation (other wagons) (€)	2,5	Rate for operation (other wagons) (€)	2,5
Rate for operation (other wagons) (€)	2,5	Rent for wagon - number of days	1	Rent for wagon - number of days	1
Rent for wagon - number of days	1	Type of locomotive	363		
Type of Add locomotive	183	Weight of locomotive (t)	87		
Weight of add locomotive (t)	120	Rate for locokm (€/h)	39,67		
Rate for add locokm (€/h)	31,32	Rate for employment/h (€)	16		
Type of locomotive	363	Energy (kW/h)	18,2		
Weight of locomotive (t)	87	Energy consumption (kw/h)	0,15		
Rate for locokm (€/h)	39,67				

Source: authors

Variant no. 1: Route Haniska pri Košiciach – Linz VoestAlpine (AT) via Žilina by the infrastructure ŽSR

Transport route in variant no. 1 was divided on the 4 parts, on which were calculated total costs. First part of transport route is section between Haniska pri Košiciach and Spisšká Nová Ves. In railway station Spišská Nová Ves is necessary adding one locomotive because of the inclined and directional track ratios. This additional locomotive is disconnected on railway station Štrba. In second section Spiška Nová Ves – Štrba was changing costs components. Third part of transport route is section between Štrba and Žilina. In railway station Žilina is necessary change the locomotive, because from Žilina to Bratislava Petržalka is an alternating traction system. Last section is between railway stations Žilina and Bratislava Petržalka. In this variant was calculated also costs for locomotive train from Štrba to Spišká Nová Ves.

Total Cost of variant no. 1 Haniska pri Košiciach - Žilina - Bratislava Petržalka are 9, 543.70 € after taking into account all changes for each section. The total costs will increase by 157,85 € because of add the locomotive train costs in direction Štrba - Spišská Nová Ves section. The total cost of this variant is 9, 701,55 €. In this variant charges for rail infrastricture is 2, 482.30 €.

Variant no. 2: Route Haniska pri Košiciach – Linz VoestAlpine (AT) via Zvolen by the infrastructure ŽSR

The second variant divided transport route into two sections, where the costs of individual sections were calculated. First section is between Haniska pri Košiciach - Zvolen. In railway station Zvolen is different traction system and it is necessary to change locomotive. The second section is the section of Zvolen - Bratislava Petržalka where the whole section is an alternating traction system. Great problem of this transport route is infrastructure conditions. In first section is big ascent and are needed 4 types locomotives 756. In second section is a needed 2 locomotives type 363.

Total cost of variant no.2. Haniska pri Košiciach - Zvole - Bratislava Petržalka are € 15,202.90 €, taking into account all changes in each section. For this variant charge for rail infrastructure is 2,077.34 €.

Variant no. 3: Route Haniska pri Košiciach – Linz VoestAlpine (AT) via Hungary by the infrastructure MAV

Transportation possibility of steel billets in variant no. 3 was divided into 2 sections, for which the costs were calculated. First section is Haniska pri Košiciach - Čaňa and the second section is Štúrovo - Bratislava Petržalka.

The total costs of the variant no. 3, on the infrastructure ZSR, are 3,734.60 €, taking into account all changes in the individual sections. Charges for Slovak rail infrastructure are 921.12 €.

Results of total costs calculation in three variants show the variant no. 1 is the most advantageous for railway undertaking. This result corresponds with current situation transportation of steel billets, ZSSK Cargo use this possibility of transportation route most often.

3.2. The Optimal Mode of Transportation of Steel Billets

The most advantageous (based on the analysis of transport characteristic and costs calculation) transportation route of steel billets is the first variant Haniska pri Košiciach – Žilina – Bratislava Peržalka. In cross–border station Bratislava Petržalka Austrian private rail operator takes over the transportation of steel billets. According to transportation analysis, from 2017, was identified that 70% transportation is via Žilina and 30% transportation is cross the Hungary. Third variant is only theoretically possibility because transport conditions are difficult and route via Zvolen has big operation costs. From January 2018 90% of transportation is going cross Žilina, one reason is provided discount of charge for rail infrastructure from ŽSR side, if rail operator uses more than 300 km of Slovak rail infrastructure. Variant cross the Hungary is used only the infrastructure has a lockout.

In the table 3 is comparative analysis selected technical-economics parameters steel billets transportation in examined variants.

Table 3

Technical-economics parameters steel billets transportation in examined variants

Parameters	**Variant 1**	**Variant 2**	**Variant 3**
Distance (km)	464.1	440.7	186.2
Backward ride of loco	Yes	No	No
Costs for backward ride (€)	157.8323	-	-
Total costs (€)	**9, 701.482**	**15, 202.91**	**3, 734.5685**
Costs per 1 km (€)	20.903	34.497	20.056
Costs per 1 tone Eas (€)	202.114	316.727	77.803
Costs per 1 tone Eamos (€)	161.691	253.381	62.242
Number of locomotives	1	4	1
	2	2	
	1		
Costs on loco (€/1km)	1.455	3.0355	0.6614
Gradient (‰)	15	16	7
Border station – stay (min)	30	30	60-80
Costs on energy (€/1km)	6.128	15.1660	5.477
Discount over the 300 km	Yes	Yes	No

Source: authors

Evaluation of table no. 3 - Comparative Analysis

According to the economic evaluation in variant no. 1 with transport distance 464,1 km is total costs 9, 701.482 €. In the variant no. 2 with transport distance 440,7 km is total costs 15, 202.91 € and third variant with transport distance 186,2 km is total costs 3, 734.5685 €. For each variant was calculated cost per 1 km, where it was found that the highest costs per 1km are in variant no.2. The increase in costs in variant 2 compared to the other variants is due to the high cost of the locomotives, because in the section Haniska pri Košiciach - Zvolen is needed 4 locomotives typ 756.The increase in energy costs, where an increase of almost half compared to other variants of tracing. To increase the cost of 1 tonne by almost 1/3 in the range of the Eas wagon, there was variant 2 compared to the other variants. By proposing a change in the wagon's order, the cost of one tonne was reduced for all variants of the trace. Disadvantage of variant 2 is also the infrastructure conditions, where there is a high gradient. This fact reflects the number of

locomotive drivers needed to transport the train with a specified weight. Variant no. 2 is possible reject for carrier's high costs for operation on this route.

Based on comparing the individual parameters from Table 3 we can say that the variant no. 1 is the most advantageous for railway undertaking, due to a negligible cost difference of 1 km and comparable energy costs. Proposal of optimal steel billets transportation were taken into account the discounts provided by the Infrastructure manager in the Slovak Republic for transport over 300 km. A next advantage of first variant is only one crossing the border, against the third variant when train must crossing three borders (Čaňa/Hidasnémeti; Szob/Štúrovo and Bratislava Petržalka). According this fact we prefer first variant as the best for railway undertaking.

3.3. Proposal to Increase of Train Capacity

To support the selected optimal mode of steel billets transportation design is supplemented by a measure concerning the possibility of increasing the transportation capacity of the train in variant no. 1.

The choice of transport vehicle depending on the type of commodity to be transported is an important element, which is the determining and conditioning factor in the efficient creation of the transport chains and also the provision of high-quality transport services [7-10]. The criterion of optimal wagon selection is its suitability for transportation depending on the goods being transported, the used transport route, the weight and train length and others parameters. The choice should always be made to meet the carrier's requirements as well as the customer's conditions. [11-13]

The following section of paper focuses on the possibility of increasing the transportation capacity of a particular train (Pn 48078) from Haniska pri Košiciach to Linz Voestalpine (AT) with a commodity transporting the steel billets by changing the train set by changing the type of wagon. Increased train transport capacity was realized on the basis of the initial load capacity indicators of the wagon.

The weight norm of the selected train is 2, 000t, it is also necessary to take into account the sections where the norm is smaller, so it is also considered with an additional locomotive on this transport route. It is also necessary to take into account the fact that at Žilina station it is to change locomotive type 131 on locomotive type 363. The change of locomotives is due to the change of one-way traction power supply system to the alternating system. Table 4 shows the basic parameters of train Pn 48078.

Table 4

Basic parameters of train Pn 48078

Pn 48078	
Weight norm (t)	2, 000
Lenght norm (m)	560
Type of locomotive	131/363/383
Sending station	Haniska pri Košiciach
Cross-border station	Bratislava Petržalka
Delivery station	Linz Voestalpine AT
Time of transportation to border station (hour)	16,03
Total transportation time (hour)	20.44
Transportation distance to border station (km)	464.1
Total transportation distance (km)	726.5

Source: Timetable ŽSR 2017/2018

Transportation time to cros-bprder station is 16.03 h, total transport time in this variation is 20.44 h. The total transport distance is 726.5 km. In Table 5 shows a comparison of selected parameters in the current wagons type Eas and the proposed variant - the wagon type Eamos.

Table 5

Increasing the transport capacity of train by changing the type of wagon

Parameters before the proposal					Parameters after the proposal					Difference of parameters		Increase of transport capacity	
Type of wagon	Number of wagons	Weight of wagons (t)	Weight of goods (t)	Weight of trains (t)	Type of wagon	Number of wagons	Weight of wagons (t)	Weight of goods (t)	Weight of trains (t)	Difference weight of wagons (t)	Difference weight of goods (t)	Number of trains	Increase values
Eas	20	460	960	1420	Eamos	20	416	1200	1616	44	240	27	6480
Eas	22	506	1056	1562	Eamos	22	457,6	1320	1777,	48,4	264	27	7128
Eas	23	529	1104	1633	Eamos	23	478,4	1380	1858,	50,6	276	27	7452

Source: authors

Current steel billets transportation is carried out in wagons type Eas with a total loading weight 57t. By combining the weight of the steel billets (12t, 24 and 36t), the maximum loading in wagons was 48 t. In order to compare the current state of transport capacity and the proposed solution, 3 model railway trains were selected for which the train's load capacity was recalculated when the type of wagon was changed. The wagon type Eamos has a total loading weight 69t on the track class D3 and D4. By combining the weight of the steel billets, a maximum load of 60t was found in this type of wagon. By the calculation, it was found, that by changing the type of wagons brings to save gross weight all three model trains and also the weight of goods to increase.

It can be said that with the same number of wagons in the train and the change type of wagon (from Eas to Eamos), the cost of rail wagons will be saved and train capacity will increase.

4. Conclusion

In conclusion we can say, by the accepting the optimal variant for the rail undertaking can this carrier save a charge for the transport route and the total cost of steel billets transportation.

A change type of wagons will increase the transport capacity at unchanged rail freight costs. The benefit of this proposal is also total time of transport, adherence to delivery times and increased transport capacity of trains.

Acknowledgements

The paper is supported by the VEGA Agency by the Project 1/0791/18"The Assessment of Economic and Technological Aspects in the Provision of Competitive Public Transport Services in Integrated Transport Systems" that is solved at Faculty of Operations and Economics of Transport and Communication, University of Žilina.

References

1. **Černá, L; Daniš, J. 2015.** Komparácia nákladov a možnosti zvýšenia prepravnej kapacity vlakov na základe vhodného výberu železničného vozňa. In Logistika – ekonomika – prax 2015[elektronický zdroj]:zborník zo 4. medzinárodnej vedeckej konferencie: Žilina 8.decembra.2015.-ISSN 1336-5851. - . [S.l.: s.n.], 2015.
2. **Černá, L.; Daniš, J. 2017.** Application of cost calculations in the tariff policy formation in railway transport. 1st ed. – Žilina: University of Žilina, 2017. – 72 s. ISBN 978-80-554-1391-4
3. **Černá, L.; Dolinayová, A.; Daniš, J. 2016.** Identification of risks in railway transport and the proposal for their price evaluate. In: Transport Means 2016, Proceedings of the 20th international scientific conference, 5-7 October, ISSN 2551-7034
4. **Černá, L.; Daniš, J.; Dolinayová, A. 2016.** Research of the development of performances in rail passenger and freight transport in comparison with selected economic indicators, In: trans & motauto world : International Scientific Journal, Year 1, iss. 2, 2016, ISSN 2367-8399, s. 16-18.
5. **Dolinayová, A. a kol. 2017.** Draft proposal of determining charges for stabling of rolling stock within the ŽSR railway network, In: 18th International Scientific Conference, LOGI 2017; Clarion Congress HotelCeske Budejovice, MATEC Web of ConferencesVolume 134, 8 November 2017, Article number 00001
6. **Dolinayova, A.; Loch, M.; Kanis, M. 2015.** Modelling the Influence of Wagon Technical Parameters on Variable Costs in Rail Freight Transport, Research in Transportation Economics 54: 33-40.
7. **Dvorak, Z. and coll. 2010.** Risk management in rail transport, University of Pardubice, Institute of Jan Perner, first edition
8. **Gašparík, J.; Ľupták, J.; Meško, P. 2016**. New Methodology for Assessing Transport Connections Depending on the Integrated Transport Network. In: 3rd International Conference on Traffic and Transport Engineering (ICTTE) Belgrade, Serbia, 388-392.
9. **Ponicky, J.; Čamaj, J.; Kendra, M. 2016**. Possibilities of Simulation Tools for Describing Queuing Theory and Operations Service Lines in Railway Passenger Transport. In the international conference on Engineering science and management. Proceedings Zhengzhou, Henan, China, Atlantis Press: 191-194.
10. **Pečený, L.; Gašparík, J.; Gáborová,** V. 2016. Development of the public tender of paths ordering in long-distance rail transport in the Slovak Republic. In: ICTTE 2016 international conference on Traffic and transport engineering, Belgrade, Serbia - Belgrade: City Net Scientific Research Center, 462-466.
11. **Stopka, O.; Ponický, J.; Chovancová, M.; Zitrický, V. 2016**. Draft method for determining the number of checking devices utilized within the regional passenger transport, Publishing of znanstveno-stručni časopis za more i pomorstvo 63: 200-203.
12. **Gašparík, J.; Lichner, D.; Blaho, P. 2008.** Základy železničnej dopravnej prevádzky. 1. vyd. – V Žiline: Žilinská univerzita, 2008. – 373 s. ISBN 978-80-8070-881-8.
13. **Stopka, O.; Černá, L.; Zitrický, V. 2016.** Methodology for measuring the customer satisfaction with the logistics services, In: Naše more = Our sea : znanstveno-stručni časopis za more i pomorstvo. - ISSN 0469-6255. – 63(3): 189-194.
14. **Kurtik, P. 2018.** Návrh optimálneho spôsobu prepravy železných brám na relácii Haniska pri Košiciach – Linz, diploma thesis, University of Žilina, 2018.

Proceedings of 22th International Scientific Conference. Transport Means 2018.

Influence of Car tire Aspect Ratio on Driving Through Road Unevenness

K. Parczewski[1], H. Wnęk[2]

[1]*University of Bielsko-Biala, Willowa 2, 43-309 Bielsko-Biala, Poland, E-mail: kparczewski@ath.bielsko.pl*
[2]*University of Bielsko-Biala, Willowa 2, 43-309 Bielsko-Biala, Poland, E-mail: hwnek@ath.bielsko.pl*

Abstract

The dimensions of the tires affect the resistance of the vehicle's movement, its traction properties and the ability to reduce the vibrations generated by road unevenness. Modern tires must provide excellent grip on dry and wet surfaces, on a straight and winding road. They should also be characterized by low rolling resistance, aquaplaning resistance, low noise emission and high durability. The general trend in car construction is the use of tires of ever larger diameters and a relatively large width. It is claimed that low aspect ratio tires are characterized by better steering capacity and greater yaw resistance, which is particularly noticeable when cornering. Tires with a higher aspect ratio improve ride comfort, reduce rolling resistance and allow higher obstacles to be overcome.
The article presents a comparison of vibrations generated by road unevenness when traversed by a vehicle equipped with tires of different aspect ratio. The tests were divided into two stages: tests of radial stiffness of the tires and road tests on drive through of road unevenness by the B class car equipped with tires of different aspect ratios. A comparison of the spectral density of the power of the vertical acceleration of the car body is provided. The Lomb-Scargle periodogram was used for the analysis.
KEY WORDS: *car tire, tire aspect ratio, road unevenness, inflation pressure, power spectral density*

1. Introduction

In today's manufactured vehicles, tires with different aspect ratio can be used interchangeably. The condition for their use is the same or almost the same diameter of the tire. It is generally known that the dimensions of tires affect the resistance of vehicle movement, its traction properties and the ability to reduce the vibrations generated by road unevenness. Requirements for contemporary tires are so high due to the requirement ensuring good grip on dry and wet surfaces, under all operating conditions. Tires should also be characterized by low rolling resistance, resistance for aquaplaning, low noise emission and durability. These requirements can be described by two general conditions - to ensure passenger comfort and safety of the vehicle [1-6, 9].

The article presents the results of research and analysis of car motion parameters while drive through single road unevenness, with triangular and rectangular shape of unevenness was selected for the analysis. The research was divided into two stages: tests on the measuring stand and road tests. The first group of tests regarding radial stiffness measurements of tires was carried out in the laboratory of the Department of Combustion Engines and Vehicles of the University of Bielsko-Biala. The second part of the research was done on the test area. A study was carried out to drive through single unevenness of the roadway by a Class B vehicle. Tests were repeated with tires of a different aspect ratio. In addition, the influence of air pressure in each type of tires was investigated. Tires of different aspect ratio were compared with each other.

2. Analiza Parametrów Opon

The radial stiffness of the tire results from: the tire's construction (including its aspect ratio), the stiffness of its individual layers and the air pressure in the tire. Tire stiffness tests were carried out in the laboratory of the Department of Combustion Engines and Vehicles in University of Bielsko-Biala [7, 8]. The radial stiffness of tires with different aspect ratio was compared. In addition, measurements of changes in tire stiffness were made during contact with road unevenness. The authors have assumed that while overcoming the unevenness of the road, at some point in time, the tire touches the unevenness on a small area (which corresponds to almost a linear contact with the road unevenness).

Subsequent analyzes concerned on drive through a single inequality of the selected shape by the vehicle. Triangular and rectangular shape of unevenness (triangle, rectangle, small square, large square) were pre-selected for research. After the preliminary tests, two inequalities were finally selected for analysis: triangular and rectangular (40x200 mm).

Spectral analysis using the least squares method called the Lomb-Scargle periodogram was used for analyzes. The Lomb-Scargel periodogram method is based on estimating the frequency spectrum from unevenly distributed data based on fitting the least squares sine curves to data samples. The results of the analyses show the power spectral density function (PSD - power spectral density function shows the strength of the variations as a function of frequency).

This method converts a series of real values into a power spectrum. The input data is a file containing the sampled time series (trial times and sample values). As a result, the Lomb-Scargel periodogram is obtained - estimated power spectral density (PSD - Power Spectral Density), presented as the PSD dependence on frequency [2, 3, 10].

The analysis results are presented below.

3. Tire Measurements, Methodology, Results

3.1. Tire Tests on the Measuring Stand

The tests were carried out in two stages first on the measuring stand and then on the road with unevenness's of different shape which were attached to road surface. Tests were carried out for tires with different aspect ratio and at air pressures from 0.10 to 0.24 MPa. The way of measuring the radial stiffness of a tire on a test bench is shown in [8].

The measurement of radial stiffness was carried out on a flat surface and on triangular unevenness. This allowed showing the difference of radial stiffness of tires on the flat surface and on unevenness. The results of measurements of static radial stiffness of tires are shown in Fig. 1.

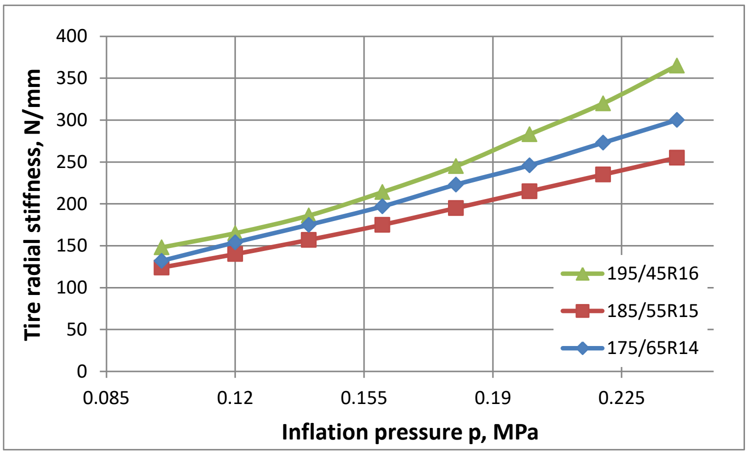


Fig. 1 Results of radial stiffness measurements of tires with different aspect ratio as a function of tire inflation pressure

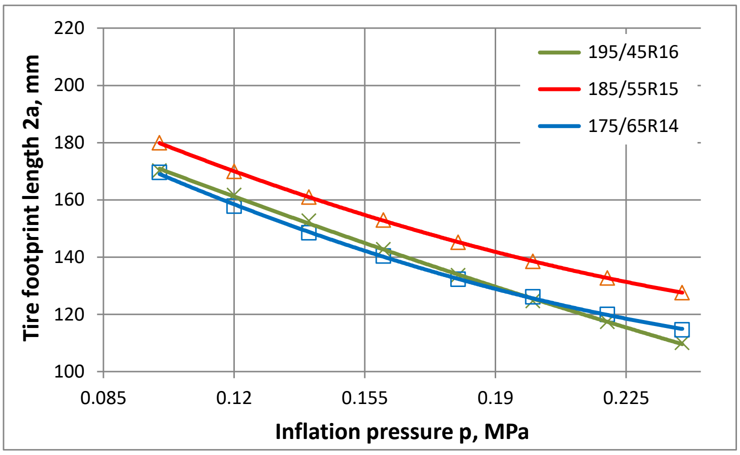


Fig. 2 The change in length of the tire footprint caused by reduction of air inflation pressure in the tire

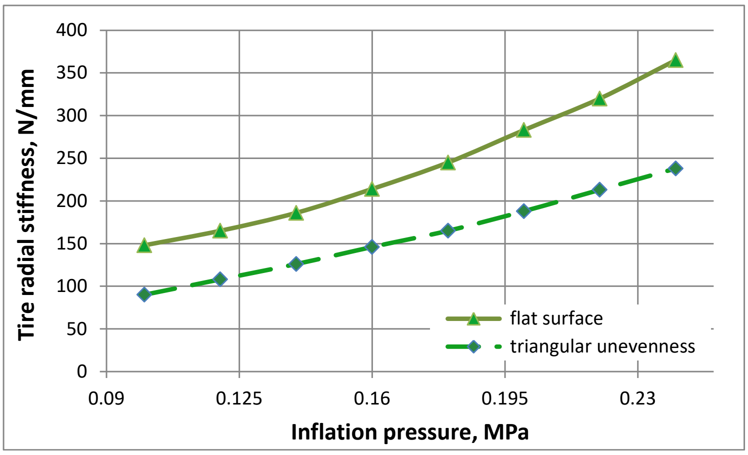


Fig. 3 Radial stiffness change of 195 / 45R16 tire caused by drive through of road unevenness

The length of the tire contact with the road surface (2a) was also determined when measuring the radial stiffness

of the tires. The change in this length caused by the reduction of tire air pressure is shown in Figure 2.

When driving through road unevenness, the tire's footprint area has changed from a flat to a linear with unevenness of the road. In this case, the radial stiffness of the tire was affected by the change in the contact area between the tire and the road and the inflation pressure in the tire. In this case, the radial stiffness of the tire decreases by ~ 25% at nominal tire inflation pressure up to 33% at reduced tire inflation pressure. The change of tire radial stiffness during drive through unevenness is shown in Figure 3.

3.2. Road Tests

Road tests consisted in driving through inequalities of various shapes. Initially, four inequalities were selected for the study: triangular, 67 mm high, square, 20 × 20 mm, 40 × 40 mm, and rectangular, 40 × 200 mm. The tests were carried out at low driving speeds of 6÷12 km/h. The method of measuring the movement of the wheel axle, suspension deflections, driving speeds and accelerations measured on the wheel axle and on the body above the wheel, are shown in Fig. 4 and in [8].

Fig. 4 The vehicle prepared for measuring wheel and body movement parameters while driving through selected unevenness

Below is shown the results of measurements of the vertical movement of the wheel and body axles and the accelerations occurring on the wheel axle and the body directly above this wheel.

3.3. Measurement Results for Different types Of Inequalities

Measurements of vehicle and wheel motion parameters were measured while driving through singular road unevenness of triangular, rectangular and square shape. The drive through the triangular inequality allowed determining the curves of the wheel axle movement trace when used tires with different aspect ratios were (Fig. 5.).

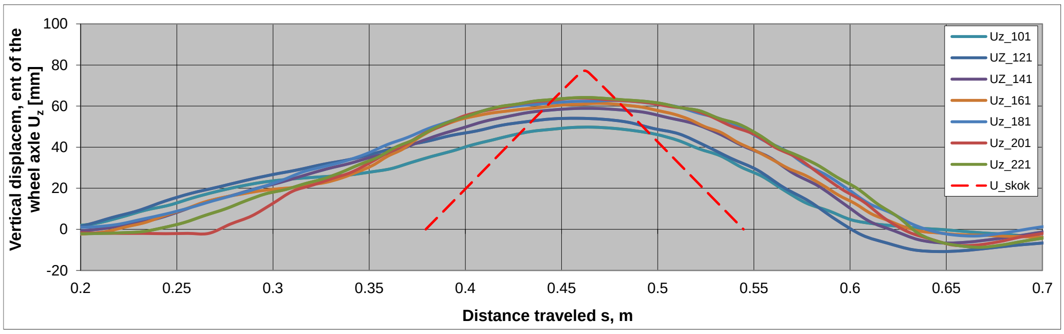


Fig. 5 Vertical movement of the wheel axis during driving through of triangular shape unevenness (tire 185/55R15)

Fig. 6 shows the maximum sheer wheel axle vertical displacement values for tires with different aspect ratio and for different tire inflation pressures. The diagram shows that at nominal air pressure, the vertical displacements of the wheel axis are similar. At lower inflation pressures, the tire aspect ratio affects the deflection of the tire, and the tires with the highest aspect ratio deforming the most and with the lowest aspect ratio deforming the least.

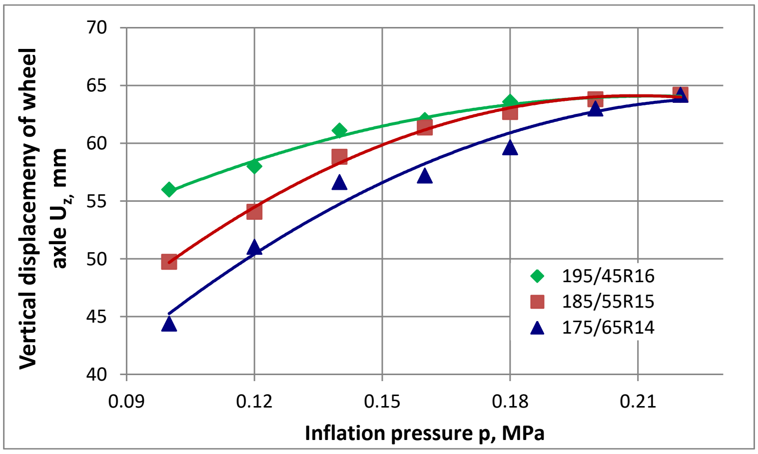


Fig. 6 Comparison of vertical displacements of the wheel axle for tires with different aspect ratio (triangular unevenness)

Fig. 7 shows the curves of the course of vertical displacements of the wheel axle for different air inflation pressures in the tire, while driving through unevenness of the rectangular shape.

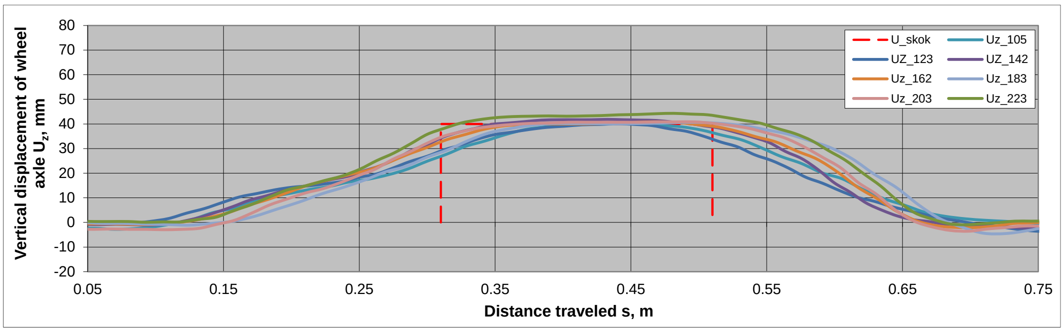


Fig. 7 Vertical movement of the wheel axis during driving through of rectangular shape unevenness (tire 195/45R16)

In the case of overcoming unevenness of rectangular and square shape, the wheel "enters" on the unevenness and the vertical displacement of the wheel axis gets a value close to its height. The lowering of the pressure in the tire causes that during the entry and exit of the unevenness, the tire deflections are higher.

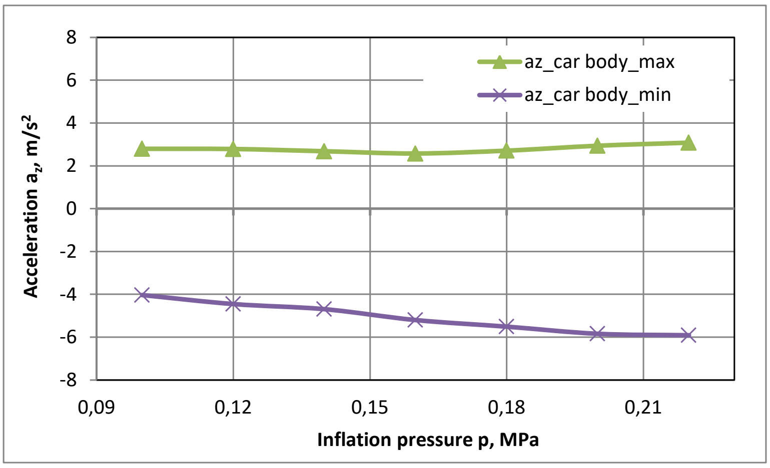


Fig. 8 The range of changes of vertical acceleration of the car body (above the wheel)

Fig. 8 shows the curves of the course of the acceleration of the car body (measured above the wheel driving through the unevenness of the road) during the movement of the suspension up and down. The changes caused by the reducing in tire pressure are relatively small.

Figs. 9 and 10 presents curves of the mean squared amplitude of power spectral density (PSD_{MSA}) of vertical accelerations of the car body, measured directly above the wheel. In the above graphs there are two extremes, wherein the first of which at a frequency of ~1,75Hz is responsible for overcoming the unevenness, the second is due to the vibration of the set car body - suspension and occurs at frequencies above 8 Hz.

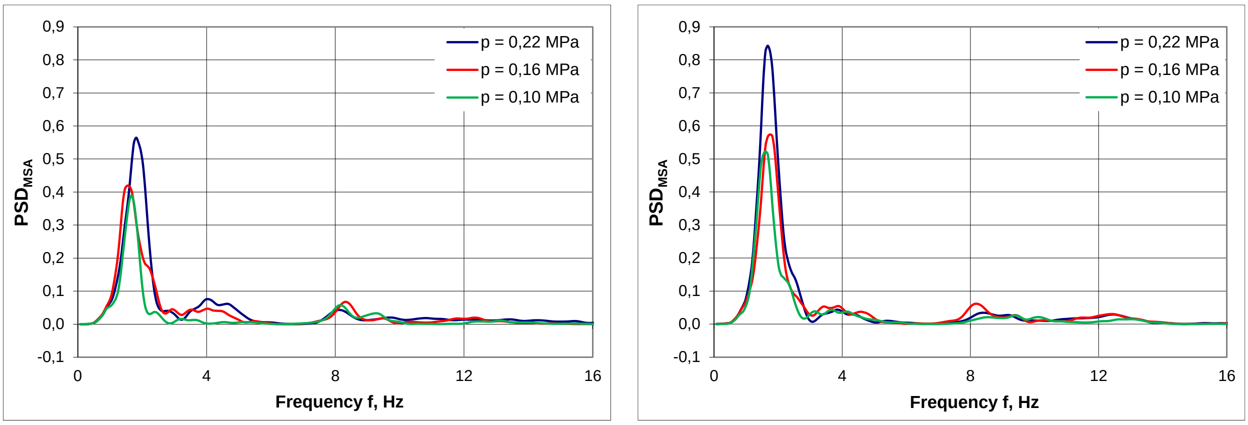


Fig. 9 Power spectral density for tires 175/65R14 (a) and 195/45R16 (b) (triangular unevenness)

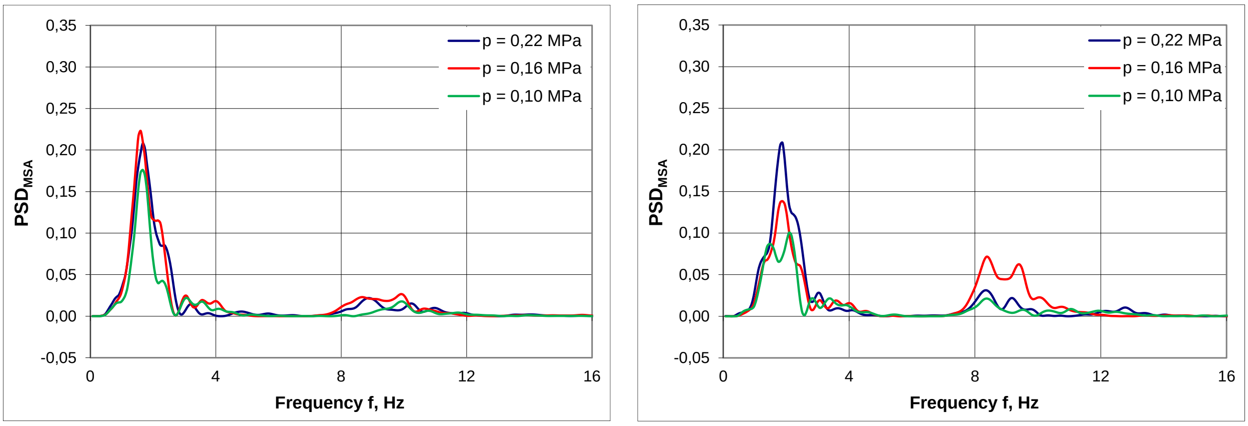


Fig. 10 Power spectral density for tires 175/65R14 (a) and 195/45R16 (b) (rectangular unevenness)

4. Summary and Conclusions

On the basis of research and analysis can be formulated the following conclusions:

1. Stiffness of the tires increases as the air pressure in the tires increases. This affects changes in the contact area of the tire with the road surface. Stiffness of the tires depends only slightly on their aspect ratio.

2. Overcoming of the road unevenness reduces the contact area of the tire with the road and increases the deflection of the tire.

3. Vertical displacements of the wheels axis during the overcoming of triangular unevenness change with the change in tire pressure. The largest displacements occur at high pressures, lower at low pressures. At low air pressures in the tire, the vertical displacements of the wheel axle are greater for tires of low aspect ratio, while the increase in air pressure reduces displacement differences for tires with different aspect ratio.

4. While overcoming the unevenness of rectangular shape maximum displacements of the wheel axis are similar for different air pressure in the tire. Differences occur only while the entry and exit of the unevenness. This causes a slight change in the maximum values of acceleration of the car body during the deflection and relaxation of the suspension.

5. By comparing the power spectral densities (PSD_{MSA}) of the vertical accelerations of the car body, it can be see that:

a. increase in air pressure in the tire influences the increase of the PSD_{MSA} value both during the overcoming of triangular and rectangular unevenness;

b. the triangular shaped obstacle produces clearly higher maximum PSD_{MSA} values, which may be due to the greater height of this obstacle;

c. the first maximum of the PSD_{MSA} value is in the frequency range 1-2.5 Hz, the second range of higher PSD_{MSA} values occurs for values above 8 Hz (in the remaining range of the frequency these values are small);

d. for tires with a lower aspect ratio the PSD_{MSA} values are higher, which is visible in the diagrams, especially for triangular unevenness.

Acknowledgments

The authors thank the management of FCA Poland, Tychy Assembling Plant for enabling the vehicle to be tested and for any assistance in their implementation.

+

References

1. **Andrzejewski, R.** 2010. Dynamika pneumatycznego koła jezdnego. Warszawa: Wydawnictwo Naukowo-Techniczne. (in Polish).
2. **Gillespie, T.D.** 1992. Fundamentals of vehicle dynamics, SAE, Warrendale.
3. **Lozia, Z.** 2000. Dynamic Vehicle Model as Road Pavement Load Generator, Engineering Transactions, Polish Academy of Sciences, Institute of Fundamental Technological Research 48/3: 243-259.
4. **Luty, W.** 2010. Badania eksperymentalne oraz opis analityczny właściwości ogumienia samochodów, Zeszyty Naukowe Instytutu Pojazdów / Politechnika Warszawska, 1/77: 7-26. (in Polish).
5. **Luty, W.** 2018. Simulation-based analysis of the impact of vehicle mass on stopping distance, Eksploatacja i Niezawodnosc - Maintenance and Reliability, Lublin 20(2): 182-189.
6. **Pacejka, H.B.** 2006. Tire and vehicle dynamics, SAE, Warrendale.
7. **Parczewski, K.; Wnęk, H.** 2015. The tyre characteristics of physical models used to investigate vehicles lateral stability, Part D: Journal of Automobile Engineering, London, 229(10): 1419–1426.
8. **Parczewski, K.; Wnęk, H.** 2017. Impact of tire inflation pressure during overcoming of road unevenness, Proceedings of 21th International Conference. Transport Means. Kaunas, Part 1: 154-157.
9. **Prochowski, L.** 2005. Mechanika ruchu samochodu, WKŁ, Warszawa. (in Polish).
10. **Zegelaar, P.W.A.** 1998. The dynamic response of tyres to brake torque variations and road unevennesses, PhD Thesis Delft University of Technology, Delft.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Wide Spectral Band Telescope for Remote Sensing Optical Surveilance with Remotely Piloted Aircraft

M. Ābele[1], E. Sharma[2], A. Treijs[3], J. Vjaters[3]

[1]*University of Latvia, Institute of Astronomy, 19 Raina Blvd., Riga, LV-1050, Latvia, E-mail: dr.maris.abele@gmail.com*
[2]*Riga Technical University, Institute of Aeronautics, Lomonosova street 1A-K1, LV-1019, Latvia, E-mail:elina.sharma.lv@gmail.com*
[3]*Photonics Ltd, Nomales street 6-25, Riga, LV-1002, Latvia, E-mail: andris.treijs@heephotonic.eu, slr_jv@latnet.lv*

Abstract

As an emerging field, remote sensing relays on remote aircraft system. This article discusses the emerging technology of Remotely Piloted Aircraft (RPA) based aerial remote sensing concept featuring a spectral sensing geo-referencing aerial imagery, precisely hyperspectral imaging spectrometer with diffraction resolution, light-capable and wide light spectrum (at least 0.4 – 2.5 μm range) telescope. Review of telescope and Remotely Piloted Aircraft carrier parameters are made. The detail study for the technical aspect of RPA is considered to make whole platform compatible with its need to meet the best resolution and results. This technology could be used in various fields like environment monitoring, agriculture, natural disaster survey, resource exploitation and much more that will be considered under its application.
KEY WORDS: *Remotely Piloted Aircraft (RPA), Remote Sensing Optical Surveillance (RSOS), Multispectral, Hyperspectral imaging, wide spectral band Telescope, Spectrometer*.

1. Introduction

This article discusses the emerging technology of RPA based aerial remote sensing concept featuring a recent appearance of on-board multispectral and hyperspectral imaging systems, e.g. [1, 3-6]. Both systems, particularly, hyperspectral images will find many different applications in resource management, agriculture, mineral exploration, environmental monitoring and many others applications. For hyperspectral imaging on RPA, firstly the engineering solutions to design of small dimensions light-capable telescopic system mated with hyperspectral camera (appropriate spectrometer with video sensor) must be made and secondly, the effective use of hyperspectral images requires an understanding of the nature and limitations of the data and of various strategies for processing and interpreting it, e.g. [2]. The RPA carrier parameters must meet as hyperspectral imager device certain dimensions and weight as well as ensuring its operation: aiming the object and tracking its relative movement. The hyperspectral imager device optical system (telescope) must provide sufficient illumination for the spectrometer's optical spectral channel's band.

2. Remote Sensing Optical Surveillance Directions

This article discusses the emerging technology of RPA based aerial remote sensing concept featuring a recent appearance of The RPA together with satellite platforms are more used RSOS in different earth and other sciences and applications directions and differs with applied on-board sensors and measurement technologies:

1. The simplest – the RPA optical video surveillance hardware and related technologies have mass applications.

2. More complex direction for aerial platforms – earth science and application as Land Management national organizations, includes more sophisticated RPA hardware and result analyses software (for RPA and satellite data acquisition) for different data: for technologies from 30 m till some cm resolution. This direction includes:

– Survey (photogrammetric) RPA systems as advanced system for cost and time saving.

– In-depth survey on RSOS instruments - which might be suitable for RPA payloads, particularly distinguishing between visible-band, near-infrared, multispectral, hyperspectral, thermal imagers, laser scanners (Lidars) and synthetic aperture radar.

Multispectral and hyperspectral imagers deal with:

Visible-band, near-infrared and multi-spectral cameras for photogrammetric and remote sensing community which have benefited from professional markets' designs for remote sensing instruments with high resolution (supplied with field cameras up to more than 50 Mpix now).

The simplest RSOS use spectra band (0.5-1.1/1.6 μm) divided into 6 – 8 discrete bands for multispectral band imaging.

A Hyperspectral camera deals with imaging narrow spectral bands over a continuous spectral range, producing the spectra of all pixels in the scene. Hyperspectral devices extract more detailed information than multispectral sensors because an entire spectrum is acquired at each pixel. Hyperspectral devices (spectrometers) is used in spectra band 0.4-2.5 μm and divided more than 250 sub-spectra bands, e.g. [2,8].

The hyperspectral spectrometer development parameters will be discussed below.

3. Telescopic System

The hyperspectral spectrometer development objectives for RPA firstly is associated with suitable telescope system design:

It must be with diffraction resolution, light-capable and wide light spectrum (at least 0.4 – 2.5 µm range) telescope and other complementary optical elements formatting with following spectrometer.

The imaging spectrometers with limited spectra range appropriate to use on RPA are obtainable in the market.

The optical telescope together with other optics (with included spectrometer) must be placed in direction stabilized gimbaled mount and must meet the currently used fixed-wing or rotary-wing RPA basic parameters:

1. Payload: not more than 10 kg (telescope with spectrometer in gimbaled tracking mount and related equipment including electronics system).
2. Telescope in gimbaled mount size: mot more than 150 × 150 × 150 mm.
3. Electric power: not more than 20W.

The telescope for imaging spectrometer was designed with its own special developed software (not published) and tested with ATMOS software [7], manufactured and tested with the following parameters:

Input aperture: 85 mm.
Focal length: 145 mm.
Aperture ratio: 1.93.
Field of view: 4º.**(**image height: 10.2 mm).
Spectra band: 0.4 - 2.5 µm.
Calculated optical resolution: see Fig. 1, Fig. 2

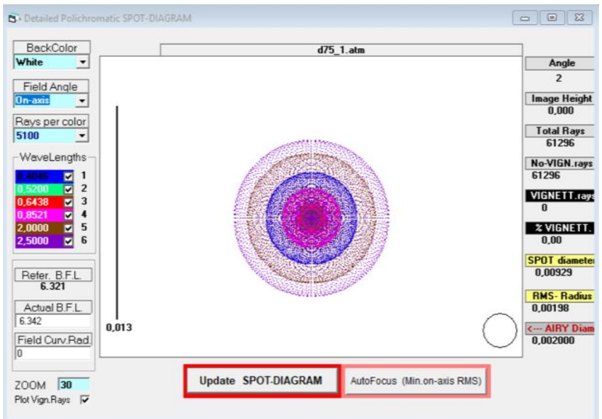


Fig. 1 Polychromatic Spot-Diagram. On-axis. Spot-diameter: <10 µm (at spectra band 0.4 - 2.5 µm).

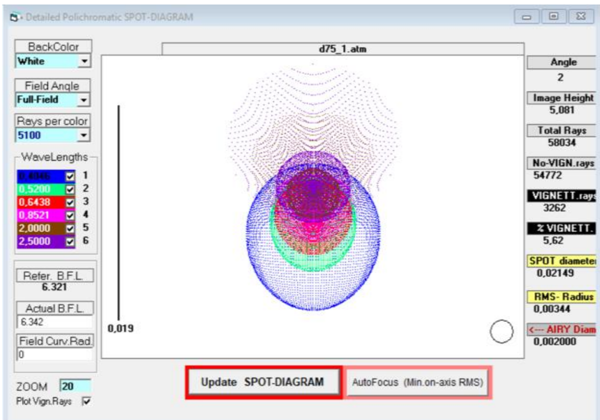


Fig. 2 Polychromatic Spot-Diagram. Full-Field. Spot-diameter on the edge of the field (4º): <22 µm (at spectra band 0.4 - 2.5 µm)

The telescope includes spectra dividing element sending firstly the visual spectra (VIS) image to visual camera focal-plane array (FPA) fixing incoming picture at the RPA flight. Secondly – sending full spectra image to spectrometer input. From the incoming VIS spectra picture analysis with the RPA flight height measurements, the data for spectrometer data analysis are acquired. The hyperspectral spectrometer measured field of view (FOV) and resolution in visual and infrared ((IR) spectra is shown in Table 1.

Table 1

Linear FOW and resolution depending of flight height

Flight height (m)	Linear FOW (m)	Theoretical linear resolution in object field (VIS) (cm)	Theoretical linear resolution in object field (SWIR and IR) (cm)
250	17.5	1.37	3.77
500	35	2.75	7.5
1000	70	5.5	15
2000	140	11	30
4000	280	22	60

4. Spectrometer

The imaging spectrometers appropriate to use on RPA are obtainable in the market, mostly with insufficient optical telescopic system. They must be completed with suitable diffraction resolution, light-capable and wide light spectrum (at least 0.4 – 2.5 µm) telescope and other optics. In this case the new spectroscope development suited for RPA fixed-wing or rotary- wing carrier is supposed (see Fig. 3). The hyperspectral spectrometer is especially designed spatial scanning device, in which each two-dimensional (2-D) FPA sensor output represents a spectrometer full slit spectrum (x, λ). Hyperspectral imaging (HSI) devices for spatial scanning obtain slit spectra by projecting a strip of the scene onto a slit and dispersing the slit image with a prism and having the image analysed per lines. With this line-scan

system, the spatial dimension is collected through RPA platform movement. This requires stabilized gimbal mount and accurate pointing information to 'reconstruct' the image. To acquire the full spectra range image the 3 different spectrum dependent FPA sensors (detectors) are used for spectra ranges VIS: 0.4 – 0.9 µm, SWIR: 0.9 – 1.7 µm and IR: 1.7 – 2.5 µm) at the same time. The spectrometer has especially designed spectra calibration system.

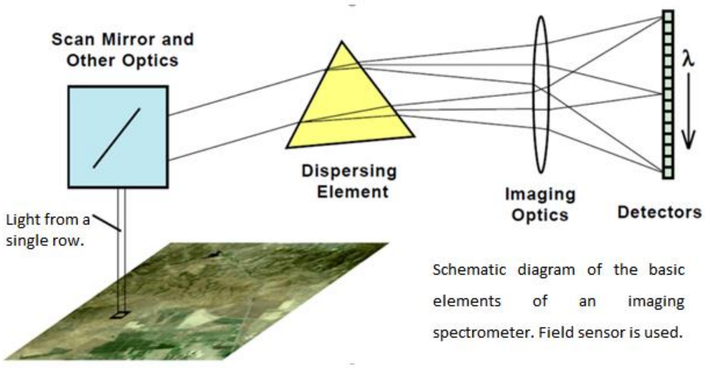


Fig. 3 Imaging spectrometer

The appropriate capacity images video data storage system used to collect synchronized incoming picture at the RPA flight, separate spectrum dependent field sensors acquired images and other RPA flight data for making post processing spectrometer data analysis.

Image analysis

Additionally for the stringent positioning, it requires that the system is designed using high quality navigation systems and using navigation-grade inertial measurement units (IMU) and of geodetic Global Positioning System (GPS) receivers.

1. Hyperspectral imaging, like other spectral imaging, it also collects and processes information from across the measured spectrum obtained for each pixel in the image of a scene, with the purpose of finding objects, identifying materials, or detecting processes.

2. The image analysis is completely dependent on the type of used Hyperspectral imaging sensor and its calibration parameters and controls, including all optics (incl. telescope optical parameters).

In this case market software is usable.

5. Remotely Piloted Aircraft for Remote Sensing

In this project the fixed-wing RPA is supposed to use. On our view would be suitable small RPA fully equipped with control and navigation systems and specialized stabilized gimbal system for telescope with spectrometer, e.g. Penguin B platform [9] or alike. This highly depends on the pre-flight operation and processing of data obtained after the flight operation.

6. Conclusion

In article are discussed the improvements in RPA carrier hyperspectral spectrometer optical system which significantly improves spectrometer sensitivity, improving the acquisition of hyperspectral data in low light conditions and shortly described selected and evaluated hyperspectral spectrometer and RPA requirements.

References

1. **Adão, T.; Hruška, J.; Pádua, L.; Bessa, J.; Peres, E.; Morais, R.; Sousa, J.J.** 2017. Hyperspectral Imaging: A Review on UAV-Based Sensors, Data Processing and Applications for Agriculture and Forestry. Remote Sens. 2017, 9, 1110, 1140. Technical Note. Preprint, available at http://www.mdpi.com/2072-4292/9/11/1110/pdf
2. **Randall, B.; Smith, Ph.D.** 2012. Introduction to Hiperspectral Imaging with TNT MIPS. Tutorial. MicroImages Inc. Preprint, available at http://www.microimages.com/documentation/Tutorials/hyprspec.pdf
3. **Urbahs, A.; Jonaite, I.** 2013. Features of the use of unmanned aerial vehicles for agriculture applications. Aviation, ISSN 1648-7788 print/ISSN 1822-4180 online, 17(4): 170-175.
4. **Urbahs, A.; Žavtkēvičs, V.** 2017. Remotely Piloted Aircraft route optimization when performing oil pollution monitoring of the sea aquatorium. Aviation, 21 (2): 70-74. DOI: 10.3846/16487788.2017.1344139
5. **Urbahs, A.; Zavtkevics V.** 2017. Remote Piloted Aircraft Using for Sampling of Oil Spill. In: Transport Means 2017: Proceedings of the 21st International Scientific Conference, Lithuania, Kaunas: University of Tehnology, pp.489-492.
6. **Yanfei Zhong, Y.; Wang, X.; Xu, Y.; Jia, T.; Cui, S.; Wei, L.; Ma, A.; Zhang, L.** 2017. MINI-UAV borne hyperspectral remote sensing: A review, Geoscience and Remote Sensing Symposium (IGARSS), Preprint, available at http://ieeexplore.ieee.org/document/8128354/
7. WEB: ATMOS software. http://www.atmos-software.it/
8. WEB: Imaging Solutions. http://www.headwallphotonics.com/spectral-imaging
9. WEB: Penguin B UAV platform. http://www.uavfactory.com/product/46

Proceedings of 22st International Scientific Conference. Transport Means 2018.

The Process of Risk Mapping Using Geographic Information Systems Focused on Infrastructure

Z. Urbancová[1], M. Lusková[2]

[1]*University of Zilina, Faculty of Security Engineering, Univerzitna 8215/1, 010 26 Zilina, Slovakia,*
E-mail: zdenka.urbancova@fbi.uniza.sk
[2]*University of Zilina, Faculty of Security Engineering, Univerzitna 8215/1, 010 26 Zilina, Slovakia,*
E-mail: maria.luskova@fbi.uniza.sk

Abstract

The paper highlights the issue of monitoring and mapping the risks using geographic information systems (GIS) in the process of mapping risks and the possibility of applying the process in railway transport. It describes the risk mapping process using GIS, spatial data processing and the possibilities of the current risk assessment methodology application in the risk mapping process. Since the railway transport significantly participates in national and international transport, it is extremely important to eliminate the risks that any emergency events might cause. For this reason, the third part of the paper is focused on an example of risk mapping process application with use of GIS technologies during accident in railway transport for which a way of depicting on the map was found. As there have been some emergency events in our country as well as in the world I consider it is important to address the issue of risk mapping in railway transport.
KEY WORDS: *infrastructure, mapping of the risk, railway transport*

1. Introduction

The development of human society is naturally accompanied by the development in the field of its protection too, because the humanity was from the beginning threatened by the extraordinary events of different nature. Level of preparedness of the society, system, or object on the crisis phenomena depends on the quality and complexity of the processing performed risk analysis. The results of the risk analysis for different kinds of incidents (e.g. spill of a hazardous substance, the long-term meteorological and hydrological statistical observation) uses the process of mapping risks. The mapping of risks is, however, feasible only through the use of the so-called geographic information systems (GIS). Risk maps containing comprehensive information on the load of the territory risks are an essential input into the processes of emergency and crisis planning and a data base for processing of the analysis of the threats to the objects. The importance of GIS s in connection with a mapping of risks is currently increasing. The concept of GIS, as a such, can be understood as a system for the processing of geographic (geo-spatial) information. It is the product of research of geo-informatics and its purpose is to process, analyse, and present geographic information. The use of GIS in practice is still expanding. They are used in the state administration and self-government in the management of its own territory, in a commercial sphere during planning of services (geo-marketing), in the records of equipment (e.g. engineering networks), in logistics, in the military field, in the field of environmental and civil protection [1]. As far as infrastructure is important to ensure the security of the state, its economy, public administration, and the vital needs of the population, it is necessary to monitor and chart the risks that its threaten. The infrastructure can be viewed from different perspectives. One of them is that we understand the infrastructure as a set of sectors ensuring the economic and social system functions. Infrastructure is divided into transport, technical, civic and public spaces. This article occupies of transport infrastructure, with a focus on railway transport and the possibility of using the process mapping of risks with the use of GIS to the risks of operating in the railway transport. As is the use of mapping risk through GIS for the territorial area wide, it is necessary occupy of this issues. The following chapter is focused on the approach to the procedure of the process of mapping risks using GIS.

2. Mapping of the Risk Using Geographic Information Systems

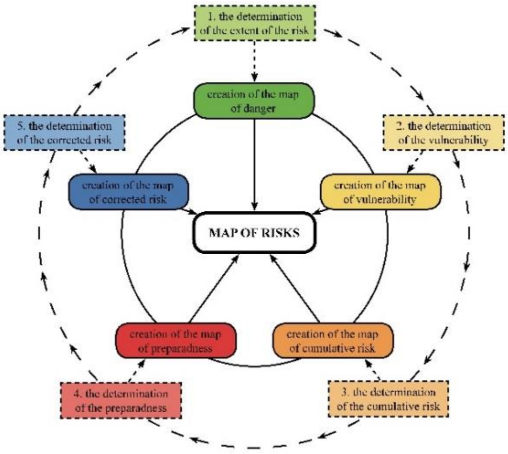
The mapping of risks is, according to the Czech author Krömer, the process through which are areas identified with different levels of risk. In the mapping of risks is carried out interaction of the manifestations of various kinds of danger with the vulnerability of the territory and with the level of preparedness of the territory [2]. The mapping of risks uses the results of the analyses of the manifestations of the possible emergencies on the territory, which can be processed on the basis of numerical model calculations (e.g. breakthrough wave), long-term meteorological and hydrological statistical observation (e.g. a snow areas), the observation of natural phenomena, and other methods.

In the mapping of the risks regards the classification and the quantification of risk in relation to the territory, that is the value expression of the risk on the map. It takes place on the basis of the technologies of the geographical information system using statistical and numerical analyses. An essential prerequisite therefore is, that into the mapping of risks can be to include only such kinds of risks, whose manifestation on a given area can be in some way expressed in

cartographic view, on the map.

For this kind of emergency there must be a layer of a GIS, or there must be data from which can be a layer of the GIS generated (for example, overview of objects of a specific kind, such as an inventory of address locations, or as an inventory of coordinates) [2].

It follows that the mapping of risks is unthinkable without the support of the GIS. The results are then presented on special maps – maps of risks which allow to identify the level and composition of risk for each part of the territory of the analysed territorial unit. The process of mapping the risks consists of five steps, which are shown in the figure below (Fig. 1), and the result of each individual step is a particular map. Next will be briefly described the individual phases. It is necessary to realize that each of the phases is preceded by the collection and evaluation of the data.



Source: the author according to [1]

Fig. 1 Process of the mapping of risk using GIS

In the first phase of the mapping of risks is a necessary value to express *the level of extent of the cumulative risk on the map base*, for which are used the maps of the individual kinds of danger, expressions of the individual types of extraordinary events plotted on a digital map. It is necessary to determine for individual kinds of the danger the numerical value of the extent of the risk, which has in the process of the cumulation of risks the importance of the comparison (weighting) coefficient.

For determination of value of the level of risks can be used multicriterial analysis by the method of expert estimates. For the needs of the mapping of risks, it is appropriate to divide the kinds of danger into two basic groups, namely: with a particular source of danger (e.g. natural flood) and without a specific source of danger (snow calamity).

In this process it is necessary to take into account also that the intensity of the action is not on the entire area of the territory constant. Such an example is the kind of danger that comes from a particular source. In areas near the source is usually the threat induced by activation of danger more acutely than in the more remote areas. Various intensity of the action of the danger is expressed using a coefficient signal (K), which is equal to or smaller than 1.

It follows that the area in which is the intensity of the action of the danger the highest, is rated by a coefficient $K = 1$ and the milder variants are expressed by the coefficient $K < 1$ [2]. In the second phase of the mapping of risks is necessary value to express on the map base *the indicator of cumulative vulnerability of the territory* as the sum of the individual elements of vulnerability.

Similarly as in the creation of maps of danger it is necessary to express different intensity of vulnerability by the coefficient of the intensity of vulnerability in the range of ≤ 1. The value is assigned to the territory with the highest level of vulnerability of a specific element, and the territory with milder vulnerability is assessed by the coefficient < 1 [2].

Creation of *the map of the cumulative risk* is the third phase and arises by interaction of the map of danger and the map of vulnerability. For the calculation of the cumulative risk, it is necessary to use the formulas that are shown in the following figure (Fig. 2).

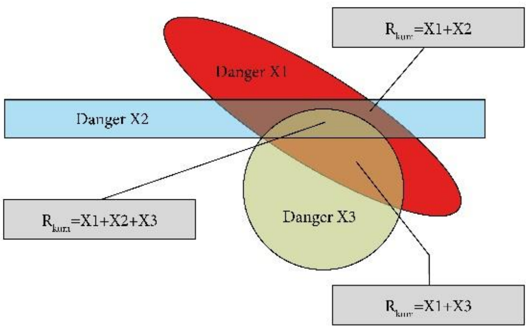


Fig. 2 Accumulation od risks [2]

Theoretically may be the maximum value equal to 1, but only in the territory for which it is determined the maximum level of risk (I_{MR} = 1) and at the same time, the maximum vulnerability (I_Z = 1) For the cartographic view it is appropriate that the files of the values contained in the intervals (0 – 1>) are included in classes, that will represent a certain interval of values, and each class will be assigned a colour.

In the fourth phase of the mapping of the risks is determined *the map of the preparedness*. The preparedness of the area can be expressed through the availability of forces and means, and the availability of means of protection of the population. A different level of availability and quality of forces and means also may be expressed using the coefficients in the range ≤ 1. The territory with the highest availability of quality of power and resources is assessed by the coefficient = 1, and for the territory with a lower availability of forces and means preparedness is reduced by a coefficient < 1 [2].

The creation of the map of corrected risk is the fifth phase of mapping of the risks and arise by the interaction of the map of the cumulative risks and the preparedness map. Corrected risk is the risk which reduces the level of preparedness and can be expressed as follows:

$$R_{kor} = \frac{R_{kum}}{P} = \frac{MR_{kum} \times Z}{P} \; [2]$$

The value of the index of the cumulative risk, as well as the value of preparedness, will be > 1, and therefore the resulting index of the corrected risk will be worth > 1. For simplification, it is necessary to recalculate the values to the range ≤ 1, where values close to 1 represent the area with the highest level of corrected risk, which indicates a territory with a high degree of danger combined with a high level of vulnerability and level of preparedness is low.

Interaction of the map of danger, the map of vulnerability and the map of preparedness arise the map of risks. Colour schemes in the index issues – the semi-closed interval (0; you 1⟩ allow to visualize the results. The importance of visualizations is shown in particular in the possibility to draw attention to the area with the higher level of risk.

3. The Processing of the Spatial Data

Already in the introduction, it was mentioned that the mapping of risks is essentially a representation of the risks to a specific area on the map. This process, however, is not feasible without the support of geographic information systems. This means that in the mapping of risks can be included only such types of extraordinary events, whose manifestations can be in some way express on the map, thus for that type of emergency there must be a GIS layer, or it must be such data, from which can be GIS layer generated [2].GIS can be seen as a set of data that have a spatial character, and program products that allow for the processing and subsequent visualization of these data. Data with a spatial character, are called the spatial data. These are data that include spatial location information, which can be viewed in space or drawn into the maps [3]. The main role in the mapping of risks is a working with spatial data, by which we express the basic variables such as danger, vulnerability, preparedness, and the resulting risk in the studied area.

During the procedure of the processing of the data is necessary in the first place, to gather the necessary data representing the specific phenomena and then process them so that they can enter into the calculation. Finally, it is necessary edit the results into its own form, that relevant information on the specific territory have been made available to end-users. It was already mentioned above, that the character of the territory in the mapping of the risks indicate the basic variables such as danger, vulnerability and preparedness.

It is for these quantities it is necessary to find the expression in the space. Each of these variables consists of the types or elements. Most of the types of danger of natural or anthropogenic character are expressed in the area. At a certain point can be the intensity of the phenomenon manifest itself stronger, weaker or not at all. It is necessary to determine the coefficient of the danger to express the intensity in the area.

Every one type of hazard is individually the one spatial layer. The same goes for the elements of vulnerability and preparedness. This layer can be built on two basic data models:

- vector data model;
- and bitmap data model.

In the process of mapping the risk is possible to use both models, in our case, has been selected vector data model.

This model works with three basic geometric elements: point, line and area (polygon). Since the process of mapping risks works on the principle of comparing and combining layers of different characteristics, it is important to have all the elements saved in the same type of geometry, and in the polygon.

From this follows the necessity to express the point and liner elements as polygons. Therefore, after the selection of appropriate data necessary to convert points and linear elements to the polygons and remove those that overlap [2]. In the following table (Table 1) there are examples of identified elements, for which he was found way of drawing on the map.

Table 1

Elements for which were found layers of the GIS

ELEMENTS	GIS LAYERS
danger	
Natural flood	5-year old, 20-year old, 100-year old , the maximum flood
Crash in rail transport	Railway network
vulnerability	
population	Population density (inhabitants per area)
Critic infrastructure	Dislocation of subjects and elements (address points)
forces and means	
Fire protection units (FPU)	Dislocation FPU, network analysis, according to the times of arrival at the place of extraordinary incident (EI)
police	Dislocation of district departments, network analysis, according to the times of arrival at the place of EI, the density of police – number of police officers per 10000 inhabitants according to the official circuits

Source: the author according to [2]

The use of the methodology for assessment of risk in the mapping of the risks

Of overview of the theoretical background shows that abroad there are methodical procedures for the mapping of risks, of which the basis was created in the framework of European project Interreg IIIC SIPROCI. One of the many outputs of the project was the manual, which was focused on the development and improvement of methods, techniques and tools for mapping and monitoring of risks. This manual inspired Czech republic which has created a methodology of mapping of risks with the use of GIS.

In the Slovak republic (SR) nowadays, there is no methodology, which could form a kind of manual needed for the process of mapping risks and its transformation into GIS, there is only the *Methodology of assessment of natural risks at the national level*, applicable in the conditions of the Slovak republic. The creation of the methodology is elaborated by the Ministry of interior of the Slovak republic (MV SR) and entered into force on 1. July 2013. The proposed methodology is focused on the evaluation of natural risks at the national level and is applicable in conditions of the Slovak republic [4].

In this methodology is during the analysis of the territory worked with elements of danger of the natural character, which means that the data can be translated into the GIS. Analysis of the area works with elements such as family homes, schools, secondary schools, social houses, administrative buildings, manufacturing plants, bus stations, railway stations, thus, each of these elements has register number (address). Some of them have a point layer of the representation, it is about significant objects (e.g. schools, social houses) or critical infrastructure. Others have a liner layer of the display, such as railway lines, power lines. These layers is necessary to convert into layers of polygon. Each of these elements has in the area of a certain surface place, which can be on the map exactly expressed. For example, the school, which is located in the building or has its own limited area (fenced); the paths have their width; the railway lines have a certain number of tracks. Using these characteristics can be all the elements in the space expressed as polygons. These data are often unavailable, therefore, it is necessary to express objects through coat zone of a certain size. This uses a simple function of GIS in the so-called buffer. These waste zones are often greater than the fair surface of that element, which may be in the mapping of the risks of an advantage.

If are the given point or line objects expressed in its accurate picture, it could happen that the visualization of the results in the smaller scales could loose small objects. And the fact that some elements of vulnerability are in the area expressed by greater surface area as in the reality, in fact, also occur larger intersections with layers of danger, which highlights the more susceptible area. The use of the coat zones at the risks of the railway infrastructure are explained on the simple example in the third chapter of the article.

If we would like transform the results of the assessment methodology of natural danger into maps of risk, it is necessary to determine the same range of coefficient expressing danger, vulnerability and preparedness. According to this principle are used in the coefficients and the indexes expressed in a range of semi-closed interval (0;1⟩, whereas the value 1 means the worst case (in the case of the preparedness the best); the value 0 means that the given area is unaffected, i.e. the value 0 is in the mapping of risks does not apply.

Map of risk arises by interaction of the map of danger, map of vulnerability, and map of preparedness, and this interaction could not take place if the range of the coefficient was different. The following chapter is aimed to highlight the necessary of importance of monitoring and mapping the risks of operating on the railway infrastructure and to highlight the importance of protecting the individual elements of this infrastructure. It also contains an example of how you can apply the mapping of risk with the use of GIS in rail infrastructure.

4. The Railway Infrastructure

Generally can be any subsystem, thus the rail transport understood as a group of interconnected and interactive parts that perform an important work or role and are part of a larger system. The basis for safe and high-quality rail transportation is a safe railway infrastructure.

It is in the basis formed by railway lines, railroad switches, other engineering structures (e.g. bridges, tunnels) and the corresponding infrastructure stations (e.g. platforms, security equipment). The railway infrastructure is, however,

necessary to be seen as functionally linked with other subsystems, e.g. subsystems of security devices, signalling devices etc.

The current network of railway tracks in Slovakia is the result of approximately 150 years of development ongoing in various state, political and economic conditions and within different economic and strategic objectives and priorities. The geographical location of Slovakia in Europe confirms the importance of the position of the railways of the Slovak republic in the European transport infrastructure, as main international railway moves have a direct link to rail lines in Slovakia.

There are some ambiguities related to safety assurance and prevention of its possible distortions [5]. Historical and statistical sources confirm that in the world there were a number of accidents in railway transport, which the consequences of the loss of life and the economic losses of large dimensions. In the following table (tab. 2) are situated a few examples of the disaster that the railway lines in the world have become.

Table 2

Examples of extraordinary events in railway transport

Place	Date	Event	The number of victims
Bagmati (India)	05.06. 1981	- the collapse of the seven wagons of a passenger train into the river	800 dead
Russia	03.06. 1989	- striking an electric railway section of the trans-siberian railway between Samara and Ufa in the USSR - the explosion of the liquefied gas from the damaged remote piping that has hit the two passing passenger trains	575 dead (181 children)
Hannover (Germany)	03.06. 1998	- the derailment of Intercity-Express – on route from Munich to Hamburg	More then 100 dead
Sri Lanka	05.02. 2009	- the tsunami in Sri Lanka and the subsequent railway disaster - a crowded train was hit by a wave of the tsunami that followed the earthquake in the Indian ocean	More than 1700 victims
Italy	30.06. 2009	- derailment of two wagons with liquid gas, which have exploded in the Tuscan port city of Viareggio	28 dead 50 wounded

Source: the author according to [6]

One of the examples of the extraordinary events in the Slovak republic which may be mentioned, a few years ago, is the frontal collision of the freight and the handling train, which claimed 6 of the dead, and become in the Budkovce in the Slovak republic. Another extraordinary event happened in the Leopoldov in 1997, when the train crashed into a stationary locomotive at a speed of 80 km/h. This event drew 1 dead and 5 injured.

In the neighbouring Czech republic in 2008 happened the misfortune, which require 8 people dead and 95 injured. An extraordinary event was preceded by an oscillating construction od repaired road flyover, which shortly fell right into the railyard. The driver immediately applied the emergency cord, but it was not possible to prevent the train from crashing into the masses of reinforced concrete in the speed of 90 km/h. This is just a few examples, but many other extraordinary events have happened. All of these disasters are an example, that it is necessary to pay attention to safety and maintain the operational capability of the railway transport. For this reason, I consider necessary to occupy with the issue of monitoring and mapping of the risks in rail transport and at the same time I include a simple example of how to use the process of mapping the risks using the GIS technologies. Already in the second chapter, it was mentioned that in the mapping of risks can be included only such kinds of extraordinary events, whose manifestations can be in some way expressed on the map and so for that kind of emergency there must be a layer of a GIS, or it has to be such data, which from which can be a layer of the GIS calculated [1]. As an example of possible applications of the process of mapping the risks with the use of GIS technologies for rail transport, I will use the accident in the rail transport, which is dealt with in the framework of the application of the project to *Mapping of risks in the Czech republic*. The bearer of this kind of hazard is the rail network and the exposed area is the surroundings of the railway line. The size of the affected area is dependent from the kind of crash. In the case of an accident with leakage of dangerous toxic substance, it is possible to characterize the impact of the effects of coat zone size of 720 metres (in the vicinity of the railway line). In the case of a spill of a petroleum substance, it is possible to use coat zone about the size of 600 meters. The size of the packing zones is derived from the size of the volumes of the tanks carrying substances by rail, and to the calculation was used the program ALOHA.

In the case of an accident of passenger or freight transport, without the large release of dangerous substances it is possible to use coat zone about the size of 100 meters. The density of traffic affects the probability of the occurrence of the crash, which is possible to express by the category of the railway line. The impacts of a possible crash also determines whether it is happening in the residential area or outside of it. The map layer of the GIS packing zones of 100, 600 and 720, it is possible to use to the designation of the coefficients of intensity of the hazard of Ki. We proceed from the assumption that in the territory of the closer railway line is the effect of a crash higher than on the territory which is far. For the determination of the source of danger K_{zdr} was used the categorization of the railway lines used in the map layer of the rail network [2]. For the representation of the vulnerability of the railways is possible to use the GIS map layer of the rail network, where it is possible to use categorization of railway for the determination of the intensity coefficient of

the vulnerability. It is necessary to convert line layer of the railway network to polygon layer using a buffer of 100 meters (Table 3) [2].

Table 3

The territory delimited by the border of a coat zone

Kind of danger	**Level/category**	**coeficient**
Railway crash	*Endangered area*	K_i
	The territory delimited by the border of a coat zone - 100 m	1
	The territory delimited by the border of a coat zone - 100 a 600 m	0,75
	The territory delimited by the border of a coat zone - 600 a 720 m	0,5
	Categories of railway network	K_{zdr}
	International corridor	1
	Corridor	0,75
	Another lines	0,5
	Trailer	0,25
The element of vulnerability	The expression of vulnerability	coeficient
Railway	Categories of railways	K_iZ
	International corridor	1
	Corridor	0,75
	Another lines	0,5
	Trailer	0,25

Source: the author according to [2]

Map of the preparedness emerge by conjuncting the maps of the individual elements of preparedness in the territory. Elements of preparedness are hospitals, warning, police, components of the integrated rescue system and other. Integrating individual maps of preparedness with the map of the danger and the vulnerability map arise the map of risks.

Risk maps, which are the result of a process of mapping risks using GIS, contain comprehensive information about the load of the area by risks and they are an essential input into the processes of emergency and crisis planning [2]. Realization of the process of mapping risks allows to get a comprehensive overview of the composition and the kind of risk for a specific territory, and in the preparatory period to set priorities for the application of anti-crisis measures.

5. Conclusion

The application of process of the mapping of risks using GIS technologies can be applied to any area where it is necessary to monitor and map the risks. From the analysis of the current and the theoretical background emerged that nowadays, in the Slovak republic insufficient attention is paid to mapping of risk using GIS and there are no methodical procedures, which would offer instructions on how to apply this process. Therefore, it is necessary to begin to occupy with this issue and take example from other countries, that are mapping the risks in this way. We can find the risks in various forms and in different areas. The article was focused on the approach to the process of mapping the risks using GIS technologies, the importance of monitoring and mapping the risks and also importance of the mapping of risks in railway infrastructure and the possibilities of how to use the process of mapping the risks and how to show the risks of operating on the rail transport to the maps.

However, any of the infrastructures is important to maintain the basic functions of the state, I consider necessary to devote to this issue, and I believe that the mapping of risk using GIS technology is a tool, which allows to be best prepared for the possible emergence of an extraordinary event.

References

1. **Urbancová, Z.** 2017. Mapovanie rizík a geograficko-informačné systémy na Slovensku. In: Bezpečnostní technologie, systémy a management 2017 [electronic source], sborník příspěvků 6. mezinárodní konference, 15. a 16. listopad 2017, Zlín, Univerzita Tomáše Bati. ISBN 978-80-7454-696-9. CD-ROM, [5] s.
2. **Krömer, A.; Musial, P.; Folwarczny, L.** 2010. Mapovaní rizik. Sdružení požárního a bezpečnostního inženýrství v Ostravě. Tiskárna Kleinwächter, Frýdek-Místek. ISBN 978-80-7385-086-9. (in Czech).
3. **Hofierka, J.; Kaňuk, J.; Gallay, M.** 2014. Geoinformatika. Univerzita Pavla Jozefa Šafárika v Košiciach, Košice. ISBN: 978-80-8152-178-2. (in Slovak).
4. **Jánošíková, G.; Hudecová, D.** 2013. Metodika hodnotenia vybraných rizík na vnútroštátnej úrovni. Ministerstvo vnútra SR, Sekcia krízového riadenia. [online cit.: 2018-01-08]. (in Slovak) Available from: www.minv.sk/?Dokumenty_na_stiahnutie_CO&subor=175547.
5. **Sventeková, E., Čičmancová, S.** 2013. Risk assessment of rail transport, In: Transport means 2013, proceedings of the 17th international conference: October 24-25, 2013, Kaunas University of Technology, Lithuania. ISSN 1822-296X. s. 228-231.
6. **Blackhouse, L.** 2010. 501 Katastrof, ktoré otřásly světem. Londýn: Bounty Books. 544 s. ISBN 978-80_7391-6091-1 (in Czech).

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Application of Altered Methodology for Bearing Strength Measurements of Unpaved Airport Surfaces

L. Cicmanec[1], J. Safranko[2], M. Petrasek[3]

[1]*University of Defense in Brno, Kounicova 65, Brno 66210, Czech Republic, E-mail: ludek.cicmanec@unob.cz*
[2]*University of Defense in Brno, Kounicova 65, Brno 66210, Czech Republic, E-mail: jan.safranko@unob.cz*
[3]*University of Defense in Brno, Kounicova 65, Brno 66210, Czech Republic, E-mail: miloslav.petrasek@unob.cz*

Abstract

This paper deals with measurements of bearing strength resistance of both grass runways and transition surfaces of paved runways such as runway end safety areas and runway strips in the environment of the Czech Air Force. The recent and current measuring techniques and methodologies are briefly described with relevant pros and cons with regards to current safety standards and trends in aviation. The authors proposed refined methodology based on results from prolonged tests and statistical analysis.
KEY WORDS: *airport, unpaved runway, runway strip, runway end safety area, bearing strength*

1. Introduction

Airport systems including technical aspects of a movement area and adjacent surfaces as well as operation procedures may be safer than ever. However, the conditions for severe incidents specifically runway excursions are still in place like the one during which B737 airliner accidently overran the runway in Pardubice airport in 2013. Fortunately, the unpaved adjacent surface had had sufficient bearing strength to provide adequate drag to stop the aircraft on a supposed distance, not causing a major malfunction or a failure of landing gear. Since no damage and casualties had been reported, the event was classified as a severe incident. Nevertheless, taking a peek in the aircraft accident database, such events are not rare in a global perspective. Sometimes they result in aircraft major damage or they cost even the higher prize, human casualties.

2. Current Legislation over Bearing Strength Measurements of Unpaved Airport Surfaces

At first, it is vital to divide unpaved airport surfaces into two separate categories, specifically into unpaved movement areas (runways, taxiways and aprons) and adjacent unpaved surfaces of a paved runway. Generally operation from unpaved runways is extremely limited and often linked to military aviation. Only a few countries permit operation of commercial aviation from unpaved surfaces preferably with gravel surfaces. The second category relates to all airports with paved runways where surfaces such as a runway end safety area (RESA) and a runway strip are established just in case of overrunning or undershooting the runway to reduce the severity of damage to an aircraft.

Runway Strip Bearing Strength Requirements

A runway strip is an area clear of objects including a graded portion, which should be so prepared as not to cause an aircraft nose gear collapse, when overrunning or undershooting the runway. In other words, the area is designed to reduce the severity of damage to an aircraft and to facilitate the movement of rescue and fire fighting vehicles. Both a runway and a stopway are included in a runway strip. The length should be extended before the threshold and beyond the end of a runway or a stopway for a specific distance for instance 60 m for an airport with a code number 2, 3 and 4. The width should extend transversely for a specific distance. However, this dimension relates to further aspects such as grading and presence of objects. Just a small portion of the runway strip is addressing the bearing strength (For instance a 75 m distance from a center line for a code number 3 and 4). Such an area should be so prepared or constructed as to minimize hazards arising from differences in load bearing capacity to airplanes which the runway is intended to serve in the event of an airplane running off the runway [1].

Runway End Safety Area Bearing Strength Requirements

Further enhancement of safe operations addressing damage minimization during take-off or landing operations has been an employment of an additional obstacle free zone called a runway end safety area. It is an extension of a runway strip and shall reach a distance of at least 90 m from the end of the runway strip. The recommended distance is in fact greater, reaching 120 m for airports with a code number 1 and 2, and 240 m for airports with a code number 3 and 4. The surface should be prepared in such a manner as to provide sufficient drag and reduce the severity of damage to an aircraft in case of overrunning or undershooting a runway. In order to meet these divergent needs aircraft manufacturers consider that a depth of 15 cm is the maximal depth to which the nose gear may sink without collapsing. Therefore, it is recommended that the soil at the depth of 15 cm below the surface should be prepared to have from 15 to 20 CBR. The reason for this is to prevent the nose gear from sinking bellow 15 cm. It was assumed that the strength

should be adequate even for the largest airliners [1]. Based on this, the supposed surfaces should be naturally compacted satisfying the strength under dry conditions, which is in fact the baseline condition the area is prepared to and assessed against. It is recognized that the strength will be affected by changes in soil humidity due to precipitation. It is anticipated that the area does not need the same strength as the associated runway, but only a few movements of a critical aircraft is considered. Slight deformation or rutting is acceptable and may be desirable to enhance deceleration. To determine whether such an area has the sufficient bearing strength, the load imposed by a critical aircraft must be considered. For commercially operated aircraft according to Canadian aviation circulations, RESA requirements can be identified as in following formula and derived into a table (See table 1). However, it is worth to point out that these values should provide sufficient support, but the rutting could be in order of 25 to 30 cm [2].

In short, it is recommended to measure bearing strength in specified areas close to a paved runway, the only accepted unit is CBR and the range should be up to 24 CBR. From our hands on experience the range should be slightly higher than this, up to 30 CBR.

$$CBR = \frac{p_{tire}}{10} . \tag{1}$$

Table 1

RESA bearing strength requirements [2]

Code letter	Wheel tire pressure p_{tire} [MPa]	CBR [%]
A and B small aircraft	0.4 – 1	
C and D medium and narrow body aircraft	1 – 1.4	14 – 20
E and F large and wide body aircraft	1.4 1.75	20 - 24

3. Bearing Strength Measuring Test Methods, Procedures and Reporting

Evaluation of Bearing Strength of Unpaved Runways According to Czech Air Force Practice

To begin with, in 1960's, the Air Forces were facing new challenges with new generation of jet aircraft coming into operational use. A part from other features, the jets were to be operated from unpaved runways. As a consequence of this, new operational procedures including daily inspection checks of bearing strength of unpaved runways were introduced. They were based on a use of a specially designed dynamic penetrometer (in the following text Airfield Dynamic Penetrometer – ADP) (See Fig. 10)) which did not measure shear resistance in pressure values, as it is known with other devices, but instead a number of blows was recorded to 10 cm and 30 cm depths. By 1980's these values had been compared with charts displaying correlation between numbers of blows and bearing strength representing directly the allowable pressure equivalent caused by an aircraft. These three charts had been empirically developed for three types of soils (clays, silts and sands) for two depths (10 and 30 cm) (see Fig. 1 and Fig. 2). In early 1990's, the methodology was even simplified by producing a simple matrix. Having added number of blows to 10 and 30 cm depths, the pressure value could be taken. The penetrometer has a needle like probe with 1 cm2 surface. The bearing resistance equivalent to pressure caused by aircraft wheels is in range of up to 1.3 MPa [3-4, 17].

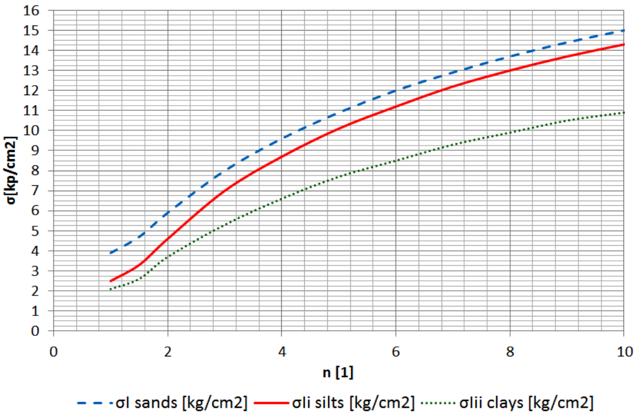


Fig. 1 Correlation of bearing strength and number of blows up to 10 cm depth [3]

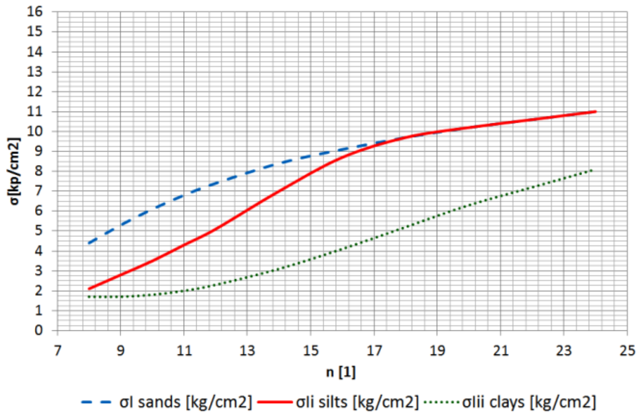


Fig. 2 Correlation of bearing strength and number of blows into 30cm depth [3]

California Bearing Ratio Test

California bearing ratio test (CBR test) was developed by California Division of Highways and later implemented by U.S. Corps of Engineers. It was the most widely used strength test in 1960's, currently known as Standard Test Method for CBR of Laboratory Compacted Soils (ASTM D1883). The test is based on a standard piston which is to penetrate soil in a mold in a laboratory. The load for penetration up to 0.1 or 0.2 in is measured and compared with the load of a sample of crashed limestone giving 100 %. Not only does the test require laboratory

conditions, but it is also time-consuming, requiring a specimen having been soaked for prolonged period. As a consequence of this, it might be considered useful for a design stage of a new airport surface only [5].

The CBR test has been adopted into a field test as well. It is currently recognized as Standard Test Method for CBR of Soils in Place (ASTM D4429). It utilizes the same procedure, but in terrain. Nevertheless, excessive forces are required to push a piston with the same dimensions to required depths. This needs additional equipment such as a reaction frame or a large truck as a support, making the application in terrain, where a strength profile into depths over 0.5 m is required, rather impractical, time consuming and laborious. In short, Original CBR test methods including the CBR field test are unfeasible to apply for a direct operation evaluation of unpaved airport surfaces [6].

Substitutive Methods and Introduction of CBR Estimate or Index

Other methods, which have the capacity to indicate the bearing strength of a required profile easily, are based on shear strength measurements. In other words, penetrometers measure the force required to deflect or penetrate the surface to a specific depth. This force is divided by an area over which it is applied, giving soil failure pressure. Such pressure values can be correlated to CBR as it is required to report strength of unpaved surfaces by CBR. It is fundamental to note that the correlations do not give absolute values, therefore an Estimate or an Index of CBR should be recorded in operation reports. [8]

Boeing High Load Penetrometer

High load penetrometer is operationally applied predominantly in North America. The test is based on penetration of a cone test probe with 50.8 mm in diameter with a steady rate into 10 cm depth. The pressure is measured and converted by a specific chart into CBR. (See Fig. 3) Despite having the results reasonably close to the ASTM D4429 regulation and references of the Boeing Company in the evaluation of many commercial and successful aircraft, the test seems to be rather narrow oriented. It requires homogenous surface layer which in practice can be achieved on gravel surfaces, but cannot be achieved on grass strips or transition surfaces. On top of this, it requires heavy machinery, a vehicle to support a hand driven hydraulic device pushing the cone probe into the surface [9].

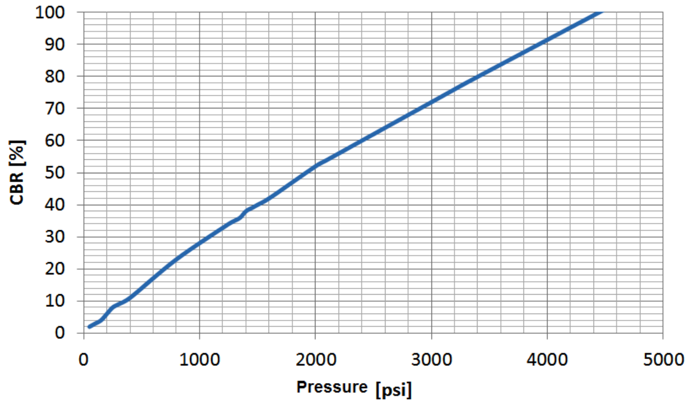


Fig. 3 Correlation of CBR and Boeing High Load Penetrometer [9]

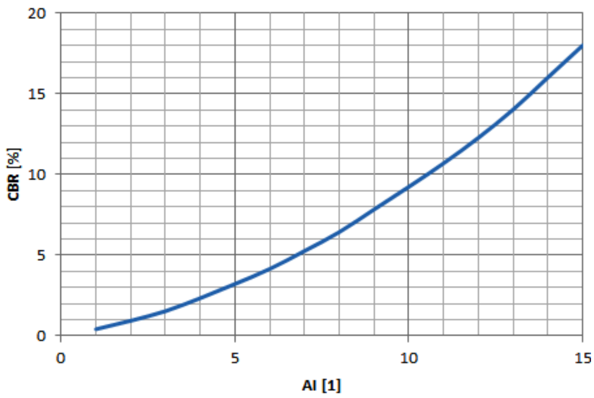


Fig. 4 Figure Correlation of CBR and airfield index AI [10]

Airfield Cone Penetrometer

An airfield cone penetrometer (ACP) was employed to evaluate bearing strength of unpaved airfield surfaces by U.S. Air Force from 1950'to 1980'. The technique is based on a probe, with a 1.27 cm diameter, 30° cone mounted on a rod, which is pushed with steady rate gradually with 5 cm increments up to 60 cm depth (See Fig. 5). The force is directly measured and reported via airfield index (AI) for an each 5 cm depth increment, which gives the final strength profile up to 60 cm depth. The range is set from 0 to 15 AI and equals to 0 – 150 lb weight. In order to issue CBR a chart or formula is issued (see Fig. 4) [7, 10].

It is a quite unpretentious technique, which could be operated by a single person. Nevertheless, it has a major limitation; it is not capable to measure high grain soils or gravels and an issued CBR range is up to only 18 CBR.

Penetrologger

A product, under the penetrologger brand name commercially produced by Eijkelkamp Agrisearch Equipment BV, principally and with its technical specifications, resembles the above mentioned airfield cone penetrometer. As a consequence of this, it shares the same drawbacks with regards to the measuring range as well as inconvenience for high grain soils or gravels. With regards to the particular CBR formula, further investigation is needed. However, it works, records and process the bearing strength values automatically with additional user friendly features including built in GPS, which even simplifies the operation handling and may preserve valuable time (see Figs. 6 and 7) [11].

In short, it appears to be quite an effective tool for airfield purposes, but just for specific known soil conditions, fine graded soils. The limited range up to 18 CBR should also be considered.

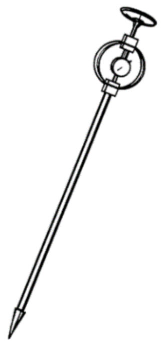


Fig. 5 Airfield cone penerometer [10]

Fig. 6 Penetrologger [11]

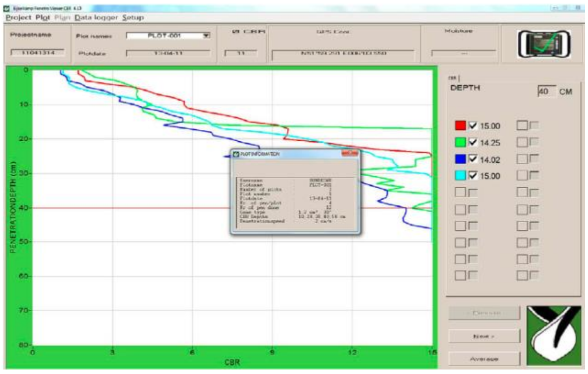


Fig. 7 Penetrologger software [11]

Dynamic Cone Penetrometer

An original dynamic cone penetrometer (DCP) was designed in 1956 to evaluate in situ cohesive soils [12], since than it has been applied to estimate CBR in shallow foundations [13]. In order to evaluate the bearing strength of unpaved runways and associated surfaces, the U.S. Air Force switched to this device from airport cone penetrometer in 1980's [14].

The device facilitates a penetration of a cone probe with 30° and 20 mm in diameter into the soil by dynamic force imposed by 8 respectively 4.6 kg hammer falling from 574 mm height [13]. For the airfield application, a vertical shear strength profile is obtained up to 1 m depth at approximately 5 cm intervals. The shear strength is expressed as a DCP index (mm per blow) which can be correlated into CBR by the use of a table or formulas. The original correlation has experienced extended research all over the world having many versions or adaptations which put the benchmark for ASTM d6951/d6951M-09/15 regulation. Further formulas for soils such as clays have been specified. The regulated equations are recommended by U.S. Army Corps of Engineers [13, 15] (see Fig. 8).

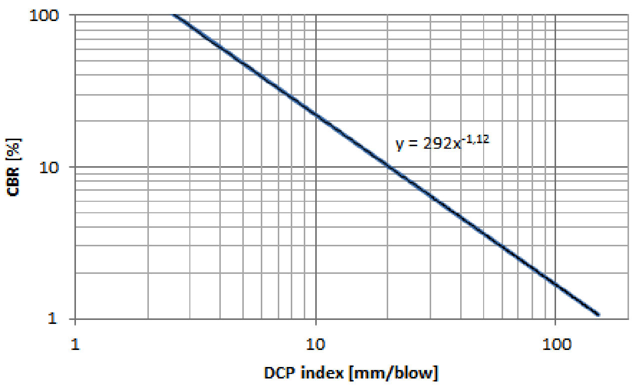


Fig. 8 Correlation of CBR and DCP index for other materials than clays [13]

To sum up, the device even with the lighter hammer can easily cover the CBR range of required bearing strength for the airfield purposes. On top of this, the formula for CBR estimation is supported by internationally accepted regulations. On the other hand, it is questionable whether the methodology for operation evaluation of unpaved airfields is not too laborious and relatively time consuming. As the methodology is designed for expeditionary use, it could possibly provide some space for refinement, adaptation and simplification for a specific airfield.

4. Correlation of Airfield Dynamic Penetrometer and California Bearing Ratio

The application of ADP over Czech military airfields has been utilized and optimized over last few decades. It has evolved into quite an effective tool to obtain a satisfactory picture of bearing capacity of unpaved airfield surfaces especially of runways on daily bases. The major drawback as mentioned above is that it does not provide CBR estimates. Having conducted detailed research of the past scientific results, an attempt to gain the correlation was done in the mid 1970's, brief information is mentioned in Mr. Nejezchleb dissertation [16].

In order to find the correlation a test was carried out on an almost homogenous test side with the area of around 30 m^2, 2 m thick, made from silts of low plasticity (ASTM D4429-09A. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)). The test was detached into 15 separate sites where 3 in-situ CBR and 5 ADP tests in 10, 20, 30 cm depths were conducted.

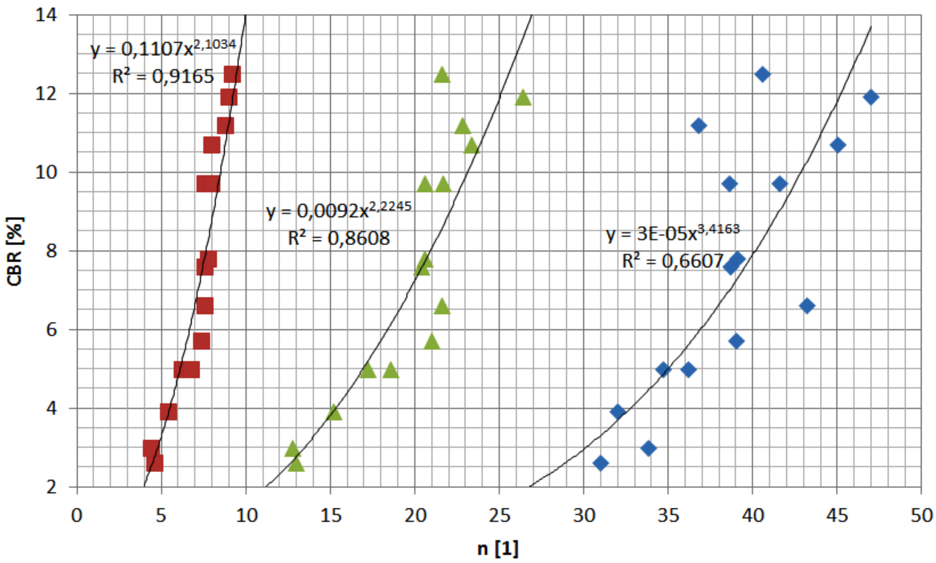


Fig. 9 Correlation of ADP and in-situ CBR

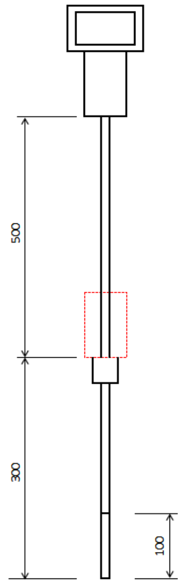


Fig. 10 Airfield Dynamic Penetrometer [3]

The results display that the CBR values and the number of blows increase gradually. Surprisingly, the dispersion in results differs with depth; it grows significantly with the depth. The correlations were sought by the use of regression analyses, least squares. Specifically, the exponential function proved the best results for all three depths (see Fig. 9). As the measured values are characterized as random numbers, which might be given by the base or character of penetration tests and tested material, there is no need to work with rather accurate coefficients and the sufficient formulas might be simplified (see Table 2). On top of this, having inspected the results at the 30 cm depth, the dispersion is extreme making the formula for this depth vague requiring further tests. The reason might be that the character of the penetration probe is a bar like, having the same diameter as an extension rod, creating additional unwanted friction forces increasing with the depth. Finally, the range of measured strength was limited to an interval from 2 to 12 CBR during the test; therefore the formulas should be valid just in this interval.

Table 2

Formula for number of blows up to 10, 20, 30 cm depths

Depth [cm]	Proposed formula	
10	$y_{10} = 0.11 * x^{2.1}$	(3)
20	$y_{20} = 0.01 * x^{2.2}$	(4)
30	$y_{30} = 3E - 05 * x^{3.4}$	(5)

To summarize, the relation between a number of blows given by ADP and in-situ CBR was successfully obtained. Not only does it require further verification, but the range from 2 to 12 CBR also seems to be insufficient. It is noteworthy that the measurements in greater depths (bellow 30 cm) inflict some space for inaccuracy due to the wide dispersion.

5. Conclusions

In closing, as shown in the paper, the bearing strength of unpaved surfaces plays a significant role in safe airport operation. The aviation authorities have specified crucial airport surfaces, their dimensions according to airport categories and issued relevant recommendations towards a bearing strength range. However, a choice of a device and methodology still remains on airport authorities. A few devices as well as methodologies have been established for these purposes in aviation. Not all have the specific characteristics to be applicable in airfield operations on daily bases. From all listed the DCP test meets all the requirements, only drawback is its time-consumption. As the DCP methodology is designed for wide range of conditions, the methodology might be refined into a specific airport condition which might be helpful in the time optimization making the use promising. The currently applied device by the Czech Air Force is an airfield dynamic penetrometer (ADP), which do not report CBR estimates. Thus a valuable correlation of the ADP number of blows and in situ CBR was obtained, despite being valid in a limited strength interval and for specific soils.

References

1. DOC 9157. 2006. Aerodrome Design Manual: Runways. 3rd ed. ICAO: International Civil Aviation Organization.
2. AC 302-015. 2013. Advisory Circular: Runway End Safety Area Bearing Strength Requirements. Canada: Transport Canada.
3. MNO. 1967. Směrnice k posuzování provozuschopnosti travnatých letišť pro provoz letecké techniky. Praha: MNO. Military publication. Czech Republic. (in Czech).
4. Let-9-3. 1985. Údržba letišť. Praha: MNO. Czech Republic. (in Czech).
5. ASTM D1883-16. 2016. Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils. West Conshohocken, PA: ASTM International.
6. ASTM D4429-09A. 2009. Standard Test Method for CBR (California Bearing Ratio) of Soils in Place. West Conshohocken, PA: ASTM International.
7. FSN 6635-900-8563. 1966. Technical Bulletin: Airfield Penetrometer. Washington, DC: Headquarters, Department of the Army.
8. AC 300-004. 2017. Advisory Circular: Unpaved Runway Surfaces. Canada: Transport Canada.
9. D6-24555. 1984. Boeing document: High Load Penetrometer Soil Strength Tester. Boeing.
10. FM 5-430-00-2, AFJPAM 32-8013. 1994. Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations: Airfield and Heliport Design,. Vol II. Washington, DC: Headquarters, Department of the Army, Department of the Air Force. [online cit. 13-6-2017] Available from: http://www.globalsecurity.org/military/library/policy/army/fm/5-430-00-2/CH122.htm
11. M1.06.15.SC.E. 2014. Penetrologger: Operating Instructions. Giesbeek. the Netherlands: Eijkelkamp Agrisearch Equipment BV, March 2014. [online cit. 2018-06-08] Available from: www.eijkelkamp.com
12. **Scala, AJ.** 1956. Simple methods of flexible pavement design using cone penetrometers. New Zealand Engineering, 11(2): 34-44. [online cit. 08-06-2018] Available from: https://search.informit.com.au/documentSummary;dn=218423931293630;res=IELENG ISSN: 0028-808X
13. ASTM D6951/D6951M-09. 2009. Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications. West Conshohocken, PA: ASTM International.
14. **Weintraub, D.** 1993. Development of an automated Airfield Dynamic Cone Penetrometer (AADCP) prototype and the evaluation of unsurfaced airfield seismic surveying using spectral analysis of surface waves (SASW) technology. Florida. Dissertation. University of Florida.
15. **Webster, S. L.; Brown, R.W.; Williams, R.W.** 1992. Report GL-92-3. Description and Application of Dual Mass Dynamic Cone Penetrometer. Washington, DC: Department of the Army.
16. **Nejezchleb, M.** 1975. Některé otázky zajištění provozuschopnosti polních a travnatých letišť pomocí membrán z plastických hmot. Brno. Dissertation. Vojenská akademie Antonína Zápotockého v Brně. (in Czech).
17. **Cibulová, K.** 2017. Instruments Used for Terrain Evaluation in the Army of the Czech Republic. In: Transport Means 2017. Kaunas: Kaunas University of Technology. p. 840-844. ISSN 1822-296X
18. **Hofmann, A.; Hoskova-Mayerova, S.** 2017. Development of applications in the analysis of the natural environment. In: APLIMAT 2016 - 15th Conference on Applied Mathematics 2016. Bratislava. Slovakia. pp. 467-481. ISBN: 978-802274531-4.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Estimation of a 15-Minute Equivalent Noise Level in the Crossroad Area

J. Sordyl[1], K. Brzozowski[2]

[1]*University of Bielsko-Biala, Willowa 2, 43-309 Bielsko-Biala, Poland, E-mail: jsordyl@ath.eu*
[2]*University of Bielsko-Biala, Willowa 2, 43-309 Bielsko-Biala, Poland, E-mail: kbrzozowski@ath.eu*

Abstract

The paper presents a problem of determining the level of noise generated by road traffic. A crossroad with traffic controlled by traffic lights located in the urbanized area, in the immediate vicinity of a complex of buildings, was selected as the research object. The set of data about traffic load, environmental parameters (temperature and relative air humidity) and the noise level was collected over a period of several months. Those data was used in order to create a model estimating the noise level at the analyzed crossroad. For this purpose, an artificial neural network of the RBF type was used.
KEY WORDS: *noise model, crossroad, artificial neural network*

1. Introduction

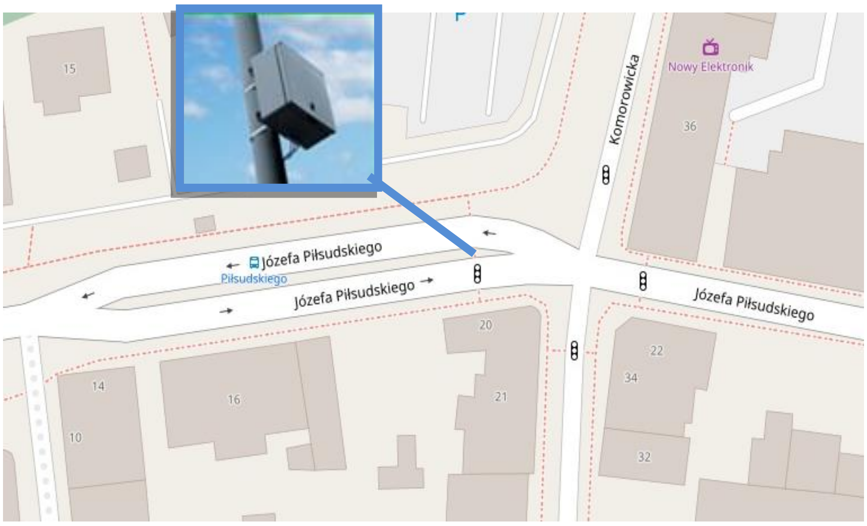
Excessive traffic load is becoming an increasingly important issue, often determining the quality of acoustic climate in urban agglomerations. Due to the inability to eliminate road traffic and its effects from city centers in total, it seems crucial to introduce monitoring of the impact of road transport on the quality of the environment. This need was noticed already in the second half of the 20th century, when the first simplified models of acoustic traffic impact began to be formulated. Currently, the problem of excessive noise level and the need for monitoring have been recognized by the European Union bodies by issuing Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002. One of its main requirements is to determine the level of exposure to environmental noise by assessment methods common for the Member States through preparation of noise maps updated every 5 years [4]. As a result, numerous models are being developed around the world to predict the acoustic impact of traffic flows based on information about traffic parameters and ambient conditions. Most of them are used on a macro scale to create acoustic maps for urban agglomerations. However, such models do not reflect the conditions prevailing in the crossroad areas. This is due to the presence of additional factors affecting the noise level in the crossroad area, such as the applied infrastructure solutions (e.g. additional stripes on the inlets cause the dispersion of noise sources and elevation above the roadway of the central island has a shielding effect) or the nature of traffic with frequently occurring changes in traffic dynamics, that should be taken into account in the model.

Some of the models used in the spatial mesoscale calculations have been attempted to adapt to be used in crossroad areas. For example, the RMW2002 model provides a correction depending on the crossroad type and daily traffic volume and the Nord2000 model takes into account a correction related to traffic dynamics. Due to the variety of solutions used in the areas of crossroads and traffic conditions, dedicated models are formulated at the same time. The approach taken by Lau and co-authors [5] is worth noting. They extended the CORTN model by splitting linear sources into sections differentiated by average traffic speeds. This correction better reflects traffic and speed-dependent conditions - the rolling noise and propulsion system noise.

Due to the large number of noise factors in the crossroad areas, it seems reasonable to develop models for specific crossroad types. Abo-Qudais and Alhiara [1] proposed a model for light-signaling crossings which, in addition to its intensity and generic structure, takes into account the gradient of the road and the texture index of the surface. In turn, in the work [6], the authors proposed a model dedicated to the crossroads with the central island. Also in this paper the authors presented a model to assess the noise level in the crossroad area. The presented model is a general one, but its application in a certain location requires prior parameterization on the basis of empirical studies.

2. The Research Object

As a research object, for which analyzes were carried out, a crossroad with one of the location of the base stations of the extended OnDynamic system network [3] was selected. The system, in accordance with the functionality assumed at the design stage, records and provides access to traffic data and values of individual indicators characterizing the measure of transport impact on the environment, including the level of noise. From among the crossroads covered by the monitoring system, located within the transport network of the city of Bielsko-Biala, the one characterized by the most unfavorable environmental conditions in comparison to the other locations [8], which is a crossroad of Pilsudskiego and Komorowicka Streets, was selected (Fig. 1.).



Source: openstreetmaps.pl

Fig. 1 Area of the monitored crossroad

The chosen location includes a crossroad with traffic controlled by traffic lights located in the urbanized area, in the immediate vicinity of the building complex. The base station of the monitoring system installed at the crossroad provides simultaneous registration of the crossroad traffic load, parameters of the ambient (temperature and relative air humidity) and the noise level in near real time. Input data enabling an attempt to create a model estimating the level of noise generated by road traffic was recorded continuously in the period from the end of July to the beginning of November. Analysis of data including continuous measurement of noise level, traffic intensity and parameters of ambient indicated the need to establish certain average measures for a selected time period. By analogy with the way of describing the variability of traffic intensity, it was decided to choose the averaging period corresponding to 15 minutes. This means that the acoustic impact level of the traffic flow in the crossroad area is represented by the value of the equivalent 15-minute noise level determined using the formula:

$$L_{Aeq15} = 10\,log\left[\frac{1}{T}\sum_{k=1}^{n} t_k 10^{0,1L_{Aeq\,tk}}\right], \tag{1}$$

where T – reference time interval equals to 15 minutes [s]; t_k – the period of recording results [s]; $L_{Aeq\ tk}$ – an equivalent sound level A at the period of recording results t_k, in decibels [dB]; n – number of periods of recording results t_k.

The other recorded values were averaged arithmetically over the same periods of time, which allowed to filter out minor fluctuations in temperature, number of vehicles passing through the crossroad and relative air humidity. The next chapter presents the general concept of the model.

3. A Model for Noise Level Estimation

In order to estimate the 15-minute equivalent noise level in the crossroad area we proposed using a feed-forward artificial neural network with radial type of neuron function (Gauss function) with single neuron on output layer. In this kind of network the base function η_i has the form:

$$\eta_i\left(\mathbf{x},\mathbf{t}^{(i)}\right) = \exp\left[-\frac{\left\|\mathbf{x}-\mathbf{t}^{(i)}\right\|^2}{2\sigma_i^2}\right], \tag{2}$$

where $\mathbf{t}^{(i)}$ – i-th centre of base function; $\mathbf{x}$ – vector of N input parameters, $\left\|\mathbf{x}-\mathbf{t}^{(i)}\right\| = \left\{\sum_{l=1}^{N}\left[x_l - t_l^i\right]^2\right\}^{\frac{1}{2}}$; σ_i – shape coefficient.

The schema of the network architecture used in our model is present in Fig. 2.

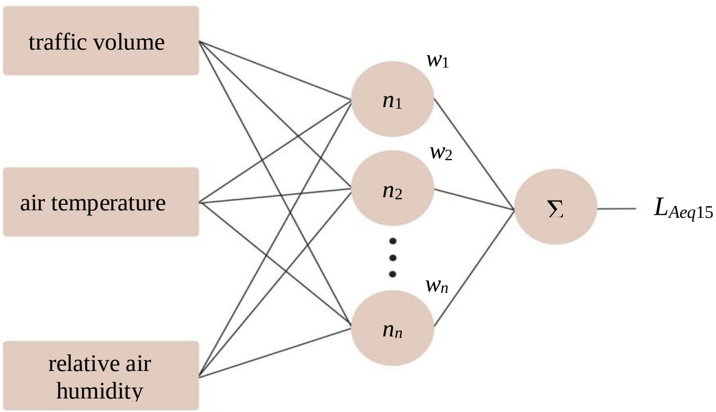


Fig. 2 Schema of the artificial neural network

In our model the input parameters (i.e. components of vector $\mathbf{x}$) are: traffic volume, air temperature and relative air humidity. As was mentioned in previous section, these input parameters are mean values for the 15-minute intervals. Expected information about the equivalent noise level is calculated on the output layer with single neuron. Taking into account a hidden layer with n elements, the value of the equivalent noise level for the RBF artificial neural network is calculated as:

$$L_{Aeq15}(x) = \sum_{i=1}^{n} w_i \cdot \eta_i \left(x, t^{(i)} \right), \tag{3}$$

where w_i – weight coefficients; $n \leq m$ – number of centers t (number of neurons on hidden layer), whilst m is a number of vectors used in training set.

The RBF type artificial neural network enable local oriented approximation in the proximity of the centers defined by value of shape coefficient σ_i. The learning procedure needs proper selection of the set of centers, their shape and weight coefficients. In the first step the cumulative version of the iterative k-means algorithm was used in order to select the set of centers. Next, the authors made an assumption that the shape coefficients will be calculated as:

$$\sigma_i = \alpha \left(\frac{1}{p} \sum_{j=1}^{p} \left\| \mathbf{t}^{(j)} - \mathbf{t}^{(i)} \right\|^2 \right), \tag{4}$$

where p is the number of closest centers taking into account in order to calculate the shape coefficient and α is an additional influence coefficient with value constant for all centers.

As was shown in the work [2] the unknown influence coefficient can be obtained as a solution of optimization task. Thus in this work the genetic algorithm was used for calculate values of parameters p and α whilst learning of the network has been performed by applying Gram-Schmidt method [7].

4. Application of the Model for the Analysed Crossroad

The data set that was used to establish and verify the accuracy of the proposed model contains several thousand records (around 5000). The recorded range of variation of the individual input quantities averaged over 15-minute periods and the equivalent noise level is shown in Table 1.

Table 1

Characteristic of the data

Parameter	Min	Max	Mean	Median
Equivalent noise level [dB]	64.6	68.8	66.5	66.6
Air temperature [ºC]	2.7	44.8	18.4	16.7
Air relative humidity [%]	8	92	65	69

In order to perform the learning of the network, the entire data set has been divided by random selection into two subsets. One subset was then used in the network learning process whilst the second subset was used to verify the quality of the model. Obviously, the network architecture and estimation accuracy are dependent on the subset used in learning process. Thus two possible cases have been considered. The obtained differences in network architecture and

accuracy of the model are presented in table 2. In order to calculate the network accuracy an acceptable error equal to 0.5 dB was assumed, i.e. difference up to 12% relative to acoustic energy levels was allowed.

Table 2

Differences in network architecture and accuracy of the model

Case considered	Subset used for learning	Subset used for verification	Value of influence coefficient α	Number of the closest centers (p) in (4)	Number of centers (hidden neurons)	Estimation accuracy
1	Subset 1	Subset 2	45.4	7	115	78.3%
2	Subset 2	Subset 1	47.6	6	130	77.8%

After analyzing data from Table 2 one can noticed, that the differences in accuracy of the model are negligible in practical point of view. The scatter plots for predicted and real values of equivalent noise levels are presented in Fig. 3.

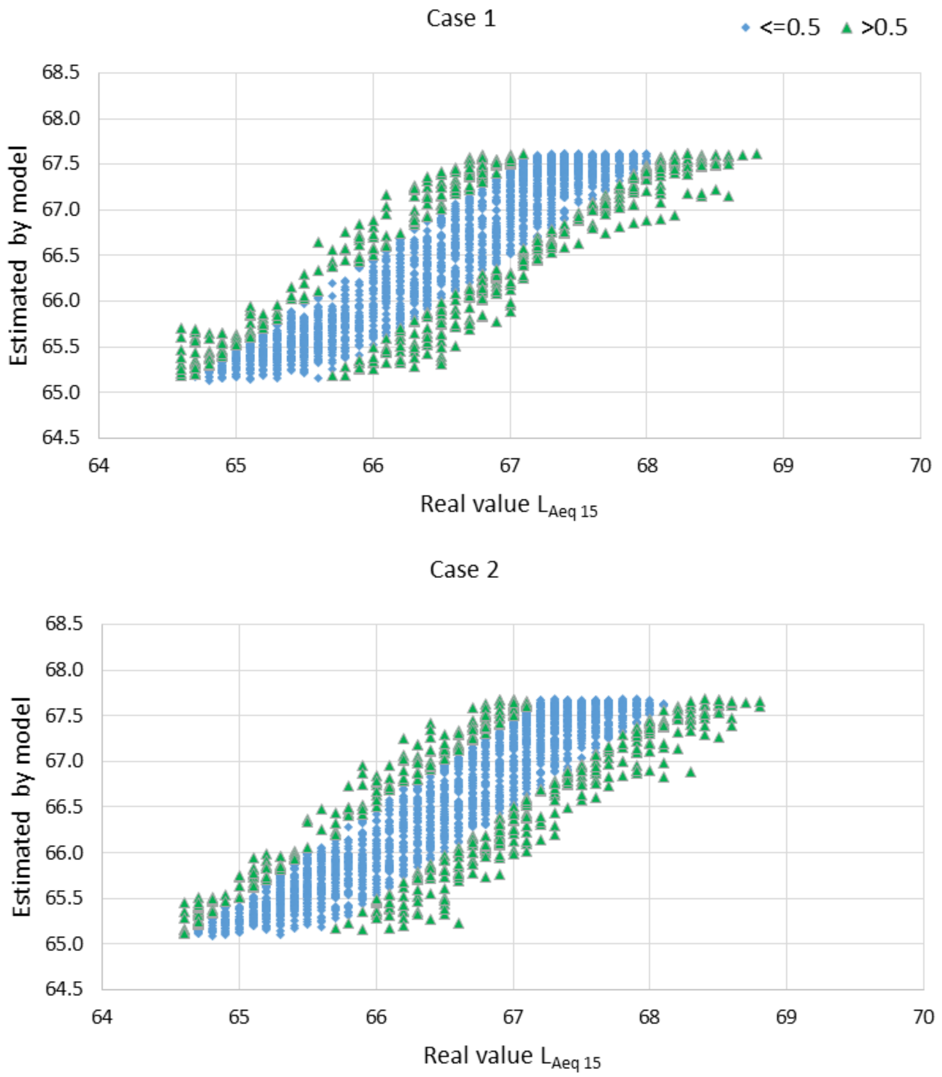


Fig. 3 Comparison of the real and estimated L_{Aeq15} with division into data that meets the criterion of acceptable error <= 0.5 and not

5. Conclusions

In order to fully understand the model accuracy, an analysis of the basic statistical measures characterizing the model output is required. Values of the statistical measures of the model output are presented in Table 3.

For the assumed acceptable error, the accuracy of the network estimation is approximately 78% for both cases considered. With the extension of the limit, the accuracy of the model increases significantly and is almost 99% for an acceptable error level of 1 dB. Moreover, maximum error equals to 1.4 dB indicate the high precision of the model, taking into account that models in which errors equal to 2.1 dB are still considered to be good [1].

Table 3

Statistical characteristics of the model output

Case considered	Mean error [dB]	Median of error [dB]	Standard deviation [dB]	Max error [dB]	Min error [dB]
1	0.32	0.28	0.24	1.44	<0.01
2	0.33	0.28	0.24	1.42	<0.01

References

1. **Abo-Qudais, S.; Alhiary, A.** 2007. Statistical models for traffic noise at signalized intersections. Building and Environment. Vol. 42, Nr 8: 2939–2948.
2. **Brzozowska, L.; Brzozowski, K.; Nowakowski, J.** 2005. An application of artificial neural network to diesel engine modelling, Book Series: IEEE International Workshop on Intelligent Data Acquisition and Advanced Computing Systems-Technology and Applications-IDAACS, p. 142-146.
3. **Brzozowski, K.; Konior, A.; Maczyński, A.; Ryguła, A.** 2016. An extension of Real-time Traffic Monitoring System with Air Quality Module, Proceedings of the 20th International Scientific Conference on Transport Means, Juodkrante, p. 75-79.
4. Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, 2002. Official Journal of the European Communities, L 189, Vol. 45
5. **Lau, A.; Lee, Y.; Dawson, B.; Mackenzie, N.** 2014. Noise modelling of road crossroads. Inter Noise 2014 Conference Proceedings, 16-19.10.2014, Melbourne, Australia.
6. **Motylewicz, M.; Gardziejczyk, W.** 2016. Wpływ charakterystyk ruchu na poziom hałasu w otoczeniu przykładowych skrzyżowań z wyspą centralną. Journal of Civil Engineering, Environment and Architecture XXXIII: 275-282 (in Polish).
7. **Osowski, S.** Sieci neuronowe w ujęciu algorytmicznym. WNT. Warszawa, 1996, (in Polish).
8. **Sordyl, J.; Brzozowski, K.** 2017. Charakterystyka lokalnej zabudowy na potrzeby lokalizacji stacji systemu monitoringu oddziaływania ruchu drogowego, Autobusy. Technika, Eksploatacja, Systemy Transportowe 6: 420-424 (in Polish).

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Analysis of the Price Trend of Low-Cost Carriers in Slovakia

P. Hanak[1], L. Socha[2], A. Tobisova[3], V. Socha[4], S. Mako[5]

[1]*Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Slovakia, E-mail: peter.hanak@tuke.sk*
[2]*Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Slovakia, E-mail: lubos.socha@tuke.sk*
[3]*Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Slovakia, E-mail: alica.tobisova@tuke.sk*
[4]*Czech Technical University in Prague, Faculty of Transportation Sciences, Konviktska 20, 110 01 Prague, Czech Republic, E-mail: vladimir.socha@fbmi.cvut.cz*
[5]*Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Slovakia, E-mail: sebastian.mako@tuke.sk*

Abstract

Pricing is one of the key areas of business activity that helps survive companies with the best profit or with the lowest possible losses. From the customer's point of view, the development of prices affects his shopping habits. The price of the product is considered to be the most important factor that affects sales. The aim of the article “The analysis of the price trend of low-cost carriers in Slovakia” is to find out the time impact on the prices of selected low-cost airlines Wizzair and Ryanair operating on the Slovak market.
KEY WORDS: *air ticket price, low-cost carrier*

1. Introduction

Pricing is one of the key areas of business activity that helps survive companies with the best profit or with the lowest possible losses. From the customer's point of view, the development of prices affects his shopping habits. The price of the product is considered to be the most important that affects sales. If the price of a product is to act on a customer and therefore also on a product, the company must pay maximum attention. The price itself is the result of a company's price strategy, largely based on its goals and mission.

2. The Principle of Pricing

Pricing, either generally or in terms of aviation, is based on several principles. Pricing in aviation can be determined by two principles, namely the dependence on competition and the nature of the market where airlines operate their lines. Using these two factors, the description of the principles is simpler and divided as follows:

- Determining the tariff conditions that lead to maximum sales due to the ability of the bidders to accept the terms, that is, they respect the restrictions on lower tariffs. This system is typical for classic carriers and the level of its use depends on the level of competition.
- Pricing that is time-dependent. We are talking about the time between the time we buy the carriage and the time when the shipment will take place. This purchase also affects the total ticket sales rate for a flight. A customer who buys a ticket later will pay more than the one who buys a ticket in advance. The transport price also represents the overall sales rate of the given shipment, since, on a more intense sale, ticket prices grow more strongly and vice versa. This sales system is used mainly by low cost airlines

At present, competition is between both low cost and classic carriers, who often use a combination of both pricing policy principles. The basis of both principles is the fact that there are passengers on the same flights (lines) whose price for the same shipment differs, that is, in prices we can see fundamental differences

3. Pricing Strategies of Low Cost Airlines

At the turn of the 20th and 21st centuries, the era of low-cost airlines began when consumers could fly without cost-effective connections. Some companies have failed despite the new business strategy, but many of them have been successful thanks to this strategy. Airline companies that have maintained their market position have benefited primarily from advertising and public relations.

Their plan and strategy are not complicated. These companies make the use of large, narrow-haul aircraft to the fore, which make them more capable. The flights are used by larger aircraft that have many seats. Passengers often pay only for a seat on the plane, other things are at an extra cost. Most low-cost airlines offer services mainly to leisure customers.

Companies also save on costs by making shorter distances, so they do not have to refuel airplane so often. Seats are booked by phone or online, which leads to a reduction in the number of employees. Companies reduce wages and also reduce overtime, food costs, handling costs by eliminating overnight stays in other countries [1].

4. Dynamic Pricing Strategy

Dynamic pricing includes a change in the price of a product or service based on variables, such as growth in demand, change of seasons, time of week or day. Other variables that influence pricing are competition, cost, accessibility. The aviation industry's goal was to increase supply and demand in a dynamic bidding strategy to maximize profits. On the other hand, the level of competition has increased, the number of services has increased, and quality has also increased.

Methods of implementing the strategy

- Segmented pricing: in such pricing, customers are willing to pay for a product or service a higher price, due to higher quality, more features, flight in a certain time.
- Top use of prices: the company, in the case of this strategy, determines the customer's higher price for the flight at peak times of the day or week compared to other times.
- Purchase time: service providers determine the price depending on when the customer is making the purchase. The closer the flight time, the higher the ticket price, and vice versa. Whoever is forced to fly in a short period of time has few options and less flexibility, so he has to pay more for the flight ticket.

With dynamic pricing, we distinguish dual customer behaviour, both elastic and non-elastic. Customers with elastic behaviour are price sensitive and react immediately to changing product pricing, so prices are falling, and demand is rising. Customers whose price does not affect and who are not sensitive to demand are less responsive to price changes. Airlines are fully aware of such behaviour by customers and subsequently set prices to maximize profit.

5. An Assessment of the Development of Low-Cost Airlines in Slovakia

Low-cost airlines have certain strategies for changing ticket prices. The subject of the article was to evaluate the development of prices for the air transport of low-cost carriers operating on the Slovak market. For this purpose, we selected two low-cost carriers Ryanair and Wizzair.

Both carriers offer from Slovakia flights to London:

- Ryanair: Bratislava (BTS) - London Stansted (STN);
- Wizzair: Kosice (KSC) - London Luton (LTN).

In our analysis, we did not compare prices because carriers operate from other geographic parts of Slovakia but analyses the price trends of the carriers, so we can find out whether they have the same strategy when determining the prices of the ticket and when it is advantageous to buy the ticket of the carrier on a given line.

Methodology

The tracking of the prices of the carriers was carried out on their website from 23rd December 2017 until 21st January 2018, which was a period of one month before the departure of the selected line. As a line, we chose London on January 22, 2018 from Bratislava and Kosice.

Tracking took place in two phases:

1. Monitor price developments in the month before departure.
2. Monitor price developments during the day in the two-week period before departure.

6. The Results

Monitor price trends in the month before departure

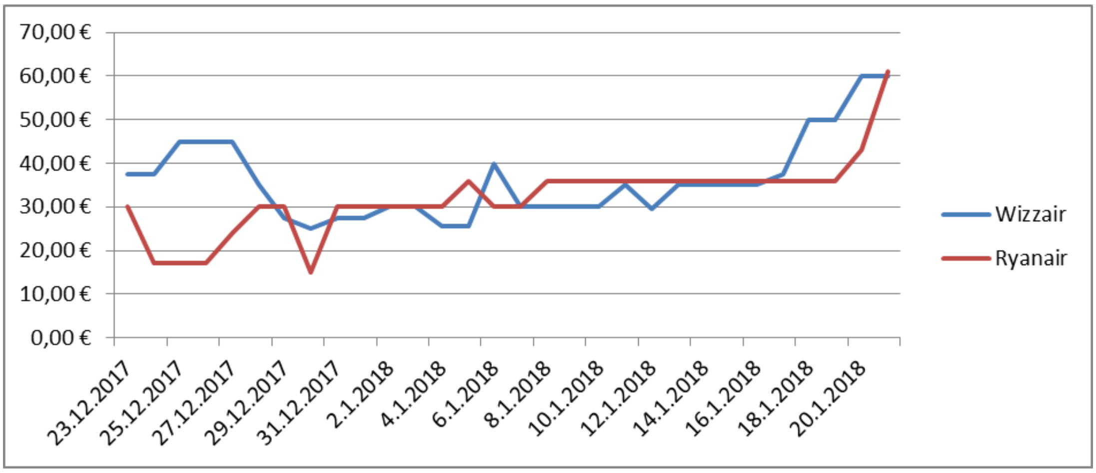


Fig. 1 Price developments on London routes by Ryanair and Wizzair

In January, carriers are expected to cut prices due to a drop-in demand for air transport. On the following chart, the trend of prices on the London routes departing January 22, 2018. The price development at Wizzair is more volatile than Ryanair, which holds prices at approximately the same level.

When comparing these companies, Ryanair can see that ticket prices have remained at the same level of time as Wizzair's ticket prices.

In the following Table, we can see the key parameters.

Table

Key price development parameters

Parameter	Air carrier	
	Ryanair	**Wizzair**
Initial price in the reference period (EUR)	29,99	37,59
Final price on departure day (EUR)	59,99	59,99
Price increase in the monitored period	100%	60%
Sold flight (Days)	1	1

Tracking price developments during the day in a two-week pre-departure period

Price tracking during the day was as follows:

- morning at 07:00;
- noon at 13:00;
- evening at 21:00.

As can be seen from the attached Figs. 2 and 3, Wizzair and Ryanair also change the cost of flights during the day. Both companies are prone to price formation by a different strategy. In most cases, Wizzair has prices higher in the evening than in the morning or noon. Ryanair, on the other hand, has lower prices in the evening compared to the morning or noon.

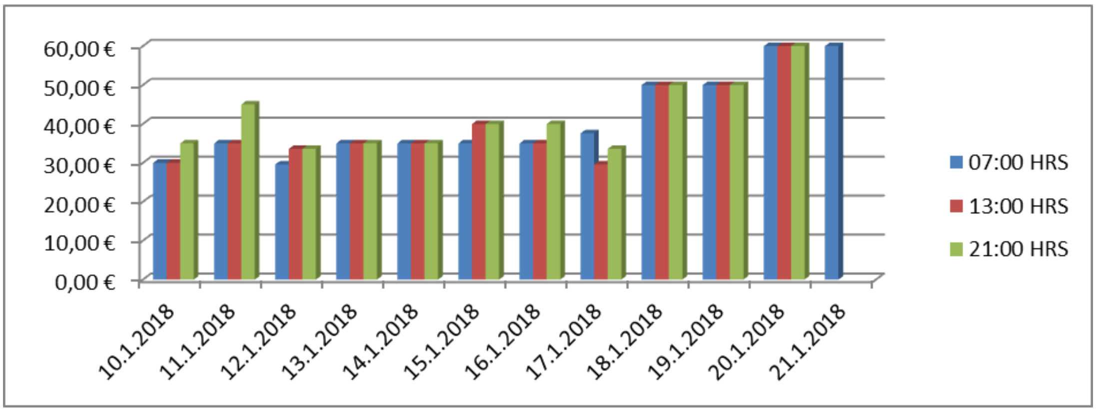


Fig. 2 Wizzair price developments during the day

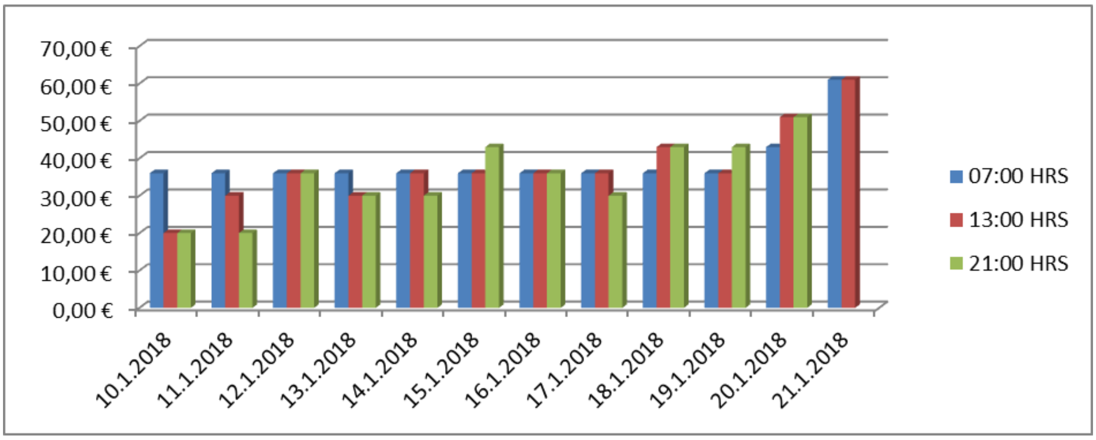


Fig. 3 Ryanair price developments during the day

7. Conclusion

In air transport, prices are market driven. There are many factors in which prices are different. They are given by the selected travel class, distance, age of passengers, number of passengers, quality of service. The goal of offering the lowest prices is to attract passengers who would not make the most of the transport. Low cost airlines have detailed plans to maximize profits. This is also the case with two selected low-cost airline companies. The basis is that the price of the ticket changes the closer the day of departure. The price changes regardless of whether the services offered remain the same. The closer the day of departure, the higher the ticket price.

Based on the analysis and tracking of ticket prices, we can say with certainty that the ticket price is rising with the approaching day of departure and the airline prices have changed in both airlines.

From the point of view of the development of airline ticket prices, the charts showed us that companies are changing ticket prices throughout the day. Wizzair uses a pricing policy where ticket prices are in many cases lower in the morning than evening ticket prices. In the last days, when the day of departure is closer, the price of airline tickets no longer changes during the day. As for Wizzair, Ryanair also changes ticket prices throughout the day. A few days before departure, however, ticket prices are still changing. Unlike Wizzair, Ryanair has several days when the price of the airline is higher in the morning than the price in the evening. To conclude, if we were not able to buy a ticket well in advance of the scheduled departure, the better time to buy a Wizzair ticket is in the morning and Ryanair in the evening.

References

1. **Prusa, J.** 2008. Svet leteckej dopravy. Prague: Galileo, ISBN 978-80-807-3938-6

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Active Technical Means of Increasing Safety in Railway Level Crossings

G. Bureika[1], V. Nozhenko[2], O. Prosvirova[3]

[1]*Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223, Vilnius, Lithuania,*
E-mail: gintautas.bureika@vgtu.lt
[2]*Volodymyr Dahl East Ukrainian National University, pr. Central 59-a, Severodonetsk, Ukraine,*
E-mail: vladymyrnozhenko@gmail.com
[3]*Volodymyr Dahl East Ukrainian National University, pr. Central 59-a, Severodonetsk, Ukraine,*
E-mail: prosvirova@ukr.net

Abstract
The article describes the structure of causality of traffic accidents at Lithuanian railways level crossings. Identification of reasons and anticipation of traffic accidents considering the safety risk factors is performed. The specific characteristics of level crossings were determined by investigating the impact of operating factors on the formation of traffic accident circumstances. By grouping the specific characteristics of the level crossings the traffic accidents were ranking according the safety level. The structure of active safety control system for ensure of level crossing secure is proposed. The algorithm of evaluation of current situation on level crossing by active safety control system is presented. The results of the research are presented in the final conclusions.
KEY WORDS: *railway crossing, traffic accident, causality, safety factors, active safety control system, operating algorithm.*

1. Introduction

Railway accident is an accident in railways or crossing with railway rolling stock, during which the people dies, at least one vehicle or cargo is damaged and causes any further harmful effects [1]. During the investigation of accident causes in railway crossings, the investigators usually name the fault of road transport vehicle driver or pedestrian [2-4]. Historically, the active technical safety means of railway crossings focus on protection of railway property, instead of making the correct decisions of car / motorcycle drivers and pedestrians [5]. The diagnostic systems made up of various intelligent controls and crossing device sensors that respond to most physical road parameters of the environment are increasingly used in the world for railway crossing safety control, as well as monitoring and control of equipment in device diagnostic systems [11].

The most usual reasons of the accidents in railway crossings are named ”inattentive driving”, ”lack of knowledge” of rules and regulations related to railway crossings of traffic participants or insufficient perception of train driving characteristics. Such description of human error is indefinite and uncertain. It is tried to integrate the issues related to human factor causing dangerous situations in railway crossings into existing psychological models. Researchers Wickens and Hollands describe the sequence of actions in human information processing model starting from early sensory perception and proceeding to processing of higher-level perception, as well as making a decision to take actions. The principle of such model can be adapted for processing analysis of received information by traffic participant approaching the railway crossing [9].

At first, the driver must detect any part of crossing safety means (for instance, signs). Second, the driver must identify them correctly as a reference to crossing. Third, after having identified the reference to crossing, the memory causes the schemes related to driving over crossing. Fourth, action scenario corresponding the existing situation in a crossing must be formed in mind based on previous knowledge. Fifth, the driver carries out the made decisions physically. It means that the driver has to reduce the vehicle speed in order to hear and visually check the approaching rolling stock on railway and, if necessary, stop the vehicle (especially, in case of uncontrolled railway crossing) [9].

The active technical means of increasing safety in railway crossings were analysed and designed in the present investigative thesis. The issues of railway crossing safety assurance were identified and assessment criteria of railway safety were established according to selected model of railway crossing safety assessment. The technical means of railway crossing safety issues were proposed.

2. Model of Railway Crossing Safety Assessment

The development of the effective preventive measures is only possible by analysing the previous accidents systematically [6, 10]. After having carried out the analysis of scientific literature, it was noticed that the model of “Chain of events“ or “Swiss cheese“ can be adapted to identify the reasons of accidents in railway crossings (see Fig. 1) and its necessary to assess three levels of obstacles to traffic accident in railway crossing: operational factors of the crossing; precondition for unsafe actions and safe actions.

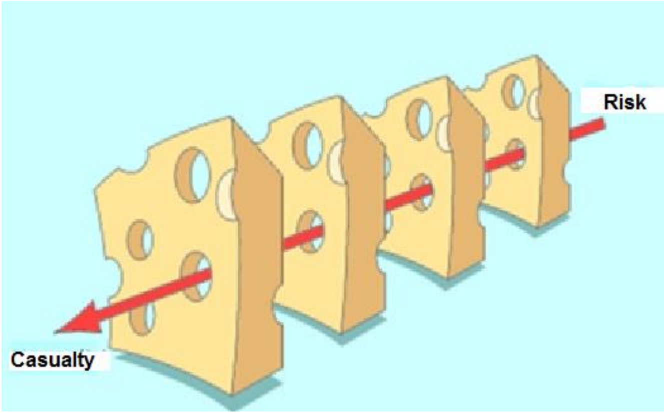


Fig. 1 Swiss cheese model depicting a coincidence of circumstances in safety means [8]

Three levels of obstacles are coherent, i.e., the highest levels affect the lower levels. The errors made in each level can filter through the "holes" in the lower level of protecting obstacles and become the reason of accident. Each level contains few causal categories, according to which the reasons of railway crossing accident can be identified.

After having analysed of scientific literature, 16 causal categories to identify the railway crossing accidents were established. The assignment of these categories to each obstacle level of railway crossing accident is presented in Fig. 2.

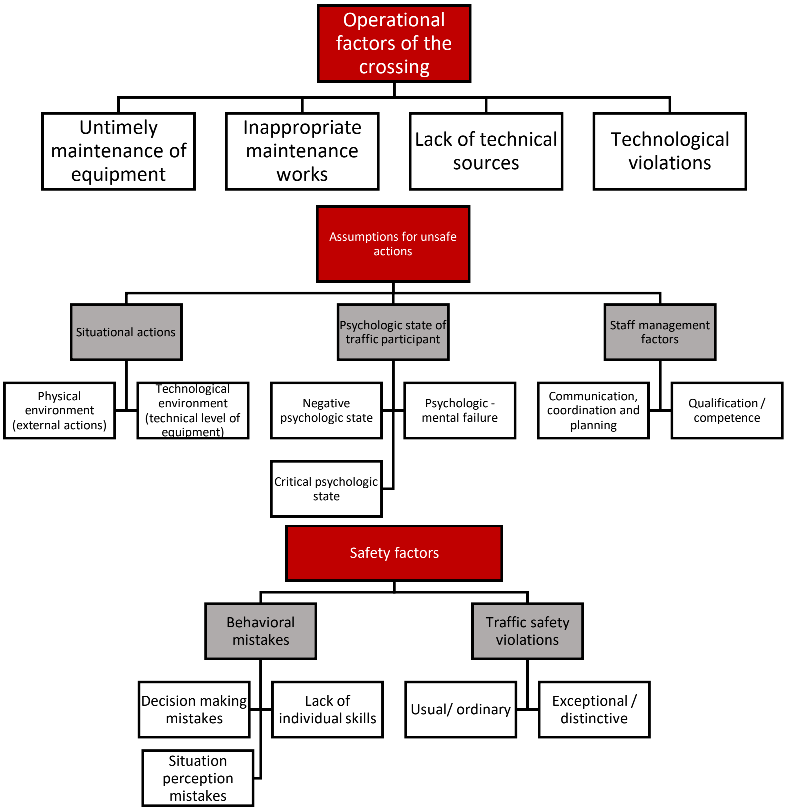


Fig. 2 Identification structure of causes of railway crossing accidents

Four causal categories of railway crossing accidents have been established for the first – highest level of obstacles to accident in railway crossing, seven categories have been established for the second level and five categories have been established for the third level.

3. Analysis of Operational Factors of Railway Crossings

Thirteen railway crossings in Lithuania where the accidents happen in 2010-2016 have been selected for the analysis of crossing operational factors. The characteristics specific for accidental crossings were identified by grouping the signs of crossing vulnerability (see Fig. 3):

1. Too sharp angle of railway and vehicle road crossing, i.e., lower than or equal to the minimum permissible angle between the crossing roads in technical requirements of crossings – 60°. It deteriorates the ability of drivers to review the situation in a crossing;

2. III and IV categories of crossings (low intensity of train and vehicle traffic, regional and district vehicle roads);
3. Two-way / multiple way crossed railway;
4. Crossings are located at sections of vehicle road with sparsely populated areas (farmsteads);
5. Insufficient visibility of approaching train for road vehicle driver if the driver is not closer than 50 m from edge rail.

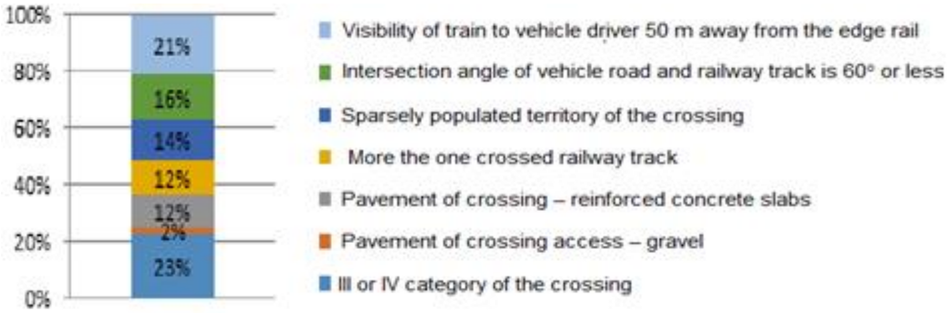


Fig. 3 The portion of the most specific characteristics of accidental crossings between all examined characteristics [7]

Various electronic systems of railway crossing safety are used for the safety of railway crossings. Currently the most innovative implemented railway crossing safety system solves only one shortage of alarm systems of operated crossings – insufficient assurance of safety in controlled crossings with automatic barriers, in case of accidental situation in a crossing and approaching train: stopped vehicle, spilled cargo, etc.

4. Designed Railway Crossing Safety System and Algorithm of its Operation

The purpose of designed active safety system of railway crossing is the solution according to developed algorithm due to situation in uncontrolled railway crossing and operative (on-line) data transfer to locomotive control devices. The information provided to information processing devices (controls) of the designed active safety system is transmitted using rail sensors instead of track chains. The active crossing safety system consists of the separate subsystems (see Fig. 4):

1) subsystem of notification about approaching train to the crossing;
2) video monitoring subsystem;
3) object identification and its parameters establishment subsystem;
4) object position analysis and decision making subsystem;
5) locomotive safety equipment subsystem.

The activated safety system identifies the type of object and establishes the parameters of road vehicle only.

Crossing safety system is activated immediately after the train enters the section of crossing approach and road sensors installed in the limits of approach sections operate.

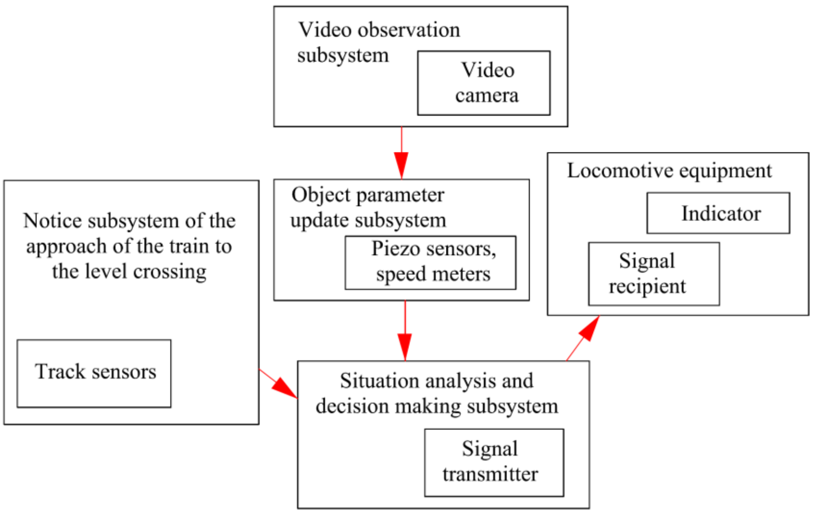


Fig. 4 Proposed structure of designed active safety system of railway crossing [7]

The length of crossing approach section L_p is calculated according to the formula, when the track chains are used to inform about the train approaching to railway crossing:

$$L_p = 0.28 \cdot v_{max} \cdot t_p , \qquad (1)$$

where v_{max} is the maximum speed of trains in a section with crossing, but $L_p = 0.28 \cdot v_{max} \cdot t_p$ is no more than 140 km/h; t_p is the time period necessary to free the crossing from vehicles ensuring unimpeded driving of train before closing of crossing. This time period is called a "message time".

In case of automatic traffic light alarm, the message time cannot be less than $t_p \geq 30$ s. ,"Message time" is calculated according to formula:

$$t_p = (t_1 + t_2 + t_3), \tag{2}$$

where t_1 is the time necessary for the vehicle to go through crossing; t_2 – equipment actuation time (t_2 = 2 s); t_3 – time leeway (t_3 = 10 s).

The time necessary for the vehicle to go through crossing (t_1) is calculated according to formula:

$$t_1 = \frac{l_p + l_a + l_s}{v_a}, \tag{3}$$

where l_p is the length of crossing equal to the distance from crossing traffic lights to the point that is 2,5 m behind the edge of the farthest rail head; l_a – calculated vehicle length (l_a = 24 m); l_s – distance from vehicle stopping place to crossing traffic lights (l_s = 5 m); v_a – calculated speed of the vehicle driving through crossing (v_a = 2.2 m/s).

The installation place of train approaching sensors from the crossing is calculated for the length of road necessary to stop the train (0,8 – 1,2) km. The additional distance is added, the time of which is necessary for the crossing system to analyse the situation in crossing, inform the operator about decision and operator's reaction. The sufficient time for this purpose is (20-30) s, i. e, until the train travels the distance of (500-800) m at average speed of 80 km/h. Therefore, train-approaching sensors must be installed at least 2 km distance to the crossing.

The proposed algorithm of railway crossing safety system operation is provided in Figure 5. The following items are necessary to forecast the accidental situation in a crossing:

1. The position of train and road vehicle at certain moment (the position of train is registered by axle counters, the position of road vehicle is registered by piezo sensors and photo capture speed meters).
2. Time for the train to approach the crossing (calculated by controls according to the details provided by road sensors).
3. Time for the road vehicle to enter the crossing (calculated by controls of object parameter establishment according to the details provided by road sensors).

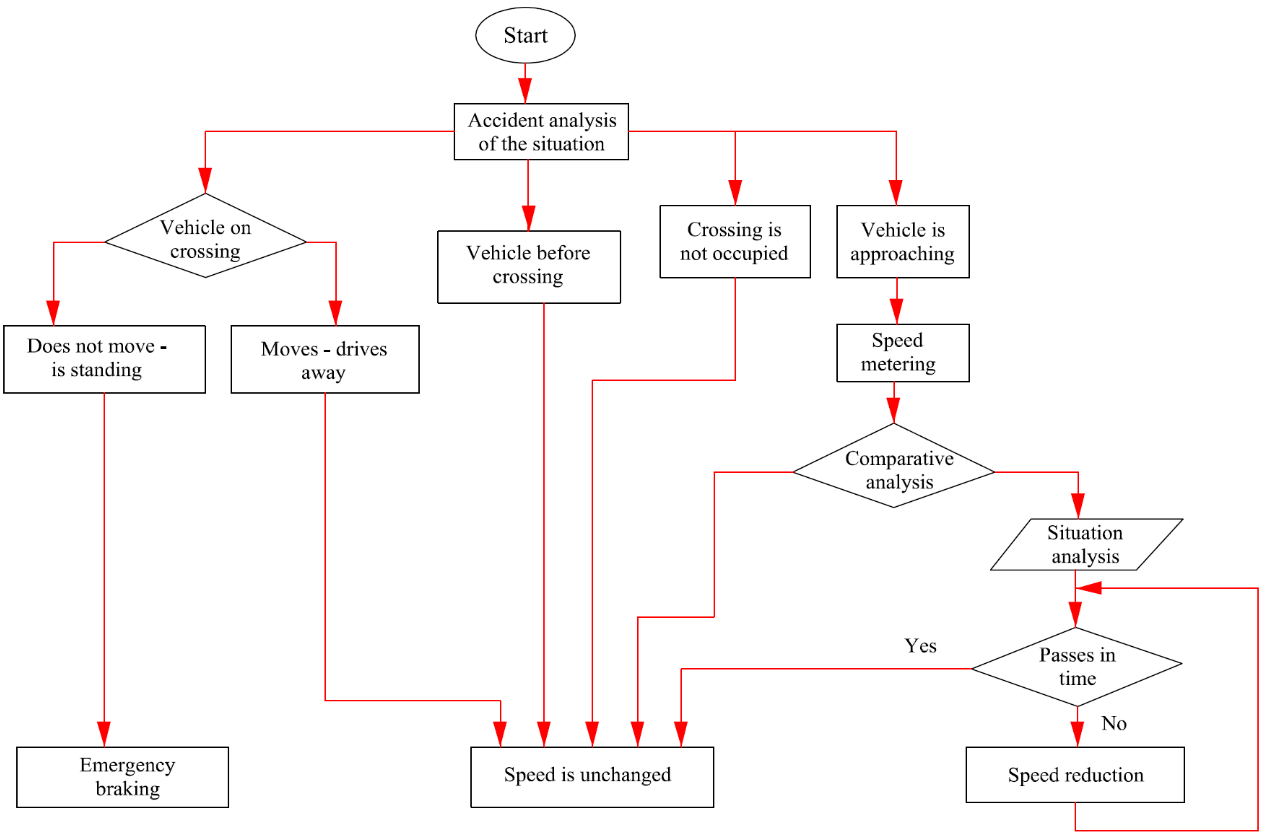


Fig. 5 Operation algorithm of railway crossing safety system [7]

The driving times of train and road vehicle are compared and algorithm of approaching train and road vehicle is made. The active safety system makes a decision of accidental (conflict) situation in a crossing.

5. Conclusions

It is proposed to use 16 causal categories to define the reasons of accidents in Lithuanian Railways crossings, considering to which the safety issues of railway crossings and possible solutions of crossing safety increase are identified.

Six criteria determining the accident risk at railway crossings are distinguished: the visibility of approaching train to vehicle driver; the 3rd or the 4th category of the crossing; two-track or multiple-track crossed railway; intersection of vehicle road and railway track at less than 60° angle; sparsely populated area (territory) of the crossing and road pavement of a crossing.

The operation algorithm of active safety system of railway crossing is created. This algorithm assesses the changing situation in a current time by approaching train and empowers to adjust the decision making of active safety system in the current time.

Acknowledgement

This research was funded by a grant (No. S-LU-18-12) from the Research Council of Lithuania. This research was performed in cooperation with the Volodymyr Dahl East Ukrainian National University, Ukraine.

Reference

1. **Bureika, G.; Komaiško, M.; Jastremskas, V.** 2017. Modelling the ranking of Lithuanian Railways level crossing by safety level, Transport problems = Problemy Transportu: International Scientific Journal 12: 11-22.
2. **Bureika, G.; Gaidamauskas, E.; Kupinas, J.; Bogdevičius, Marijonas; Steišūnas, S.** 2017. Modelling the assessment of traffic risk at level crossings of Lithuanian railways, Transport 32(3): 282-290.
3. **Danciu, B.; Popa, C.; Micle, M.I.; Preda, G.** 2012. Psychological risk factors for road safety. Procedia – Social and Behavioral Sciences, Romania 33: 363-367.
4. **Evans, A.W.** 2011. Fatal accidents at railway level crossings in Great Britain: Accident Analysis and Prevention 43: 1837-1845.
5. **Liang, C.; Mohamed Ghazel, M.; Cazier, O.; El-Koursi, E-M.** 2017. Predicting motorcycle crash injury severity using weather data and alternative Bayesian multivariate crash frequency models, Accident Analysis & Prevention 108: 181-188.
6. **Mok, S.C.; Savage, I.** 2005. Why has safety improved at rail-highway grade crossings? Risk Analysis. Risk Analysis, 25(4): 867-881.
7. **Ratkelis, R.V.** 2018. Lietuvos geležinkelių pervažų saugumo didinimo priemonės. Baigiamasis magistro darbas. VGTU. 67 p. [In Lithuanian language].
8. **Reason, J.** 2000. Safety paradoxes and safety culture, Injury Control and Safety Promotion 7(1): 3-14.
9. **Wickens, C.D.; Hollands, J.G.** 2000. Engineering psychology and human performance, New Jersey: Prentice-Hall Inc. 118 p. ISBN-0-321-04711-7.
10. **Wiegmann, D.A. & Shappell, S.A.** 2003. A human error approach to aviation accident analysis: The human factors analysis and classification system. Burlington, VT: Ashgate Publishing, Ltd. 165 p. ISBN 0-7546-1875-7.
11. **Zhang, Zh.; Trivedi, Ch.; Liu, X.** 2017. Automated detection of grade-crossing-trespassing near misses based on computer vision analysis of surveillance video data. Available online 15 December 2017. doi.org/10.1016/j.ssci.2017.11.023.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Possibilities of Introduction of Automated Operation on the Prague Metro

J. Siroky[1], P. Nachtigall, E. Tischer, K. Magdechová[2]

[1]*University of Pardubice, Faculty of Transport Engineering, Studentska 95, 532 10, Pardubice, Czech Republic, E-mail: jaromir.siroky@upce.cz*
[2]*University of Pardubice, Faculty of Transport Engineering, Studentska 95, 532 10, Pardubice, Czech Republic, E-mail: petr.nachtigall@upce.cz; erik.tischer@student.upce.cz; katarina.magdechova@student.upce.cz*

Abstract

The issue of automated metro is a modern trend in rail transport. Its utilization is still mainly in the field of urban underground railways. This article shows the possibilities that the Prague Metro has in its expansion of the D line in the area of automatic operation. As a sub-part, the possibility of switching the current operation to automatic in the modification of the security equipment and new vehicles, was also solved. However, this option seems complex and inefficient.

This article focuses on automated metro operation systems, their basic requirements and functions. There is also a definition of various degrees of automation and a description of differences in functions of individual types. This article gives also a basic overview of functions, which are necessary for an automated metro operation system. In the second part, the article provides for an analysis of automated metro systems in the world. The last part deals with various types of interlocking systems for the automated metro operation system, including their basic functions.
KEY WORDS: *automated metro, operation systems, rail transport, vehicles, basic functions*

1. Introduction

As the preparations of the development of new metro line D are under way, ideas regarding the technical and technological aspects of the new line began springing up in the academic realm. It is the first time that an unmanned train set is about to be used. The concept of operation, as well as the exact route in the city centre are still to be finalised. This is why a diploma thesis [1] was drawn up at the Faculty of Transport Engineering at the University of Pardubice, aiming to simulate various concepts of operation on this new line including technical measures for the operation of unmanned train sets and the influence of ETCS L3 on the track capability. Unfortunately, due to a lack of input data, it was not possible to write this thesis in such a form. As an alternative, the thesis deals with the verification of functionality of SW Opentrack for metro operation, as well as a simulation of the ETCS L3 train control system on metro line C.

This article presents a summary of the first part of the research, defining and analysing various unmanned metro operations worldwide and covering the application of the chosen technology on the track of metro line B. The authors are now preparing another section of the article, which is about to cover the simulation of the current operation and the transition to ETCS L3 and its impact on the peak interval and transport capacity.

2. Automatic Metro Operation

Automatic operation refers to the operation of driverless or fully unattended self-propelled trains on a reserved guide track. Driverless train operation (DTO) is a type of operation with staff on board the train who are not responsible for driving the train or monitoring the track ahead of the train. In these cases, the operations staff are in charge of ensuring safe boarding and alighting of passengers, or, as the case may be, for a safe dispatching of the train from the station. Furthermore, there are unattended trains (UTO), in which there is no staff on board the train and all the functionalities are ensured by technical equipment [2].

2.1. Grades of Automation

Urban railway systems may be classified into a total of five grades of automation. Each particular grade exactly defines which basic functions need to be fulfilled (are the responsibility of) the operations staff and which are ensured by an urban guided transport management and control system. Table 1 provides an overview of basic functionalities for individual grades of automation. Functions ensured by operations staff are highlighted in red, functions ensured by EGTMS are highlighted in green.

In addition to these basic functions, the system may ensure other functions as well. However, these are not mandatory and do not affect its classification. The classification of particular optional functions is at the sole discretion of the railway manager and carrier [2]. At the same time, the IEC 62290 standard defines four basic grades of automation ranging from GoA1 to GoA4. These standards are included in Czech technical standards, such as ČSN EN 62267 (Railway applications – Automated urban guided transport (AUGT) – Safety requirements), ČSN EN 62290 – 1 (Railway applications – Urban guided transport management and command/control systems - Part 1: System principles and

fundamental concepts) and ČSN EN 62290 – 2 (Railway applications – Urban guided transport management and command/control systems – Part 2: Functional requirements specification).

Table 1

Grades of automation

Basic train operation functions		**Manual operation without automatic protection**	**Non-automated operation**	**Semi-automated train operation**	**Driverless train operation**	**Unattended train operation**
		GoA0	**GoA1**	**GoA2**	**GoA3**	**GoA4**
Ensure safe movement of train	Ensuring safe route					
	Ensuring safe train separation					
	Ensuring safe speed					
Driving the train	Acceleration and braking		By operations staff only, or by UGTMS in part			
Supervising the guideway	Obstacle collision prevention					
	Prevent collision with persons on tracks					
Supervising passenger transfer	Opening passenger doors					
	Prevent injuries to persons between cars or in the boarding area					
	Ensure safe starting conditions					
Train operation	Putting the train in service /taking the train out of service					
	Supervising the status of the train					
Ensure detection and management of emergency situations	Fire/smoke detection and derailment detection, detection of the loss of train integrity, passenger emergency signalling					UGTMS or staff in OCC

Source: [2] edited by authors

For classification purposes of this paper, systems with a grade of automation ranging from GoA0 to GoA2 are considered to be conventional train operation systems and grades GoA3 to GoA4 are considered to be automatic operation systems. As far as track-side equipment is concerned, it is not necessary for all parts of the track to be equipped with applications of identical grade of automation. The extent of security shall always be at the highest possible level as far as the compatibility of track-side and vehicles is concerned. The individual grades of automation have to be fully mutually compatible [3].

Train operation without automatic train protection (GoA0) – while guiding/driving the train only by vision, without automatic protection, the train operator is fully responsible for the safe movement of the train. The train operator is not supervised by any technical equipment. The operations staff is responsible for the safety and efficiency of track-side operation and railway transport. Train, station and track-side signalling equipment may be set up for this grade of automation of operation, but this is only optional [3].

Non-automated train operation (GoA1) – during non-automated train operation, the train operator is at the front of the vehicle and supervises the track-side ahead of the train. Acceleration and braking of the train are carried out by the train operator, who drives the train based on the observable signals of wayside signalling or based on signals passed on to the position of the train operator. The train operator drives the train under the supervision of automatic train protection. This equipment may be of a point, line or semi-line type and carries out supervision as specified. This supervision entails vigilance supervision, train speed supervision and the supervision of compliance with signalling. In this case, the operations staff is fully responsible for the safe departure of the train from the station, including the closing of the train doors [3].

Semi-automated train operation (GoA2) – for semi-automated operation, the train operator only supervises the safe movement of the train. The train operator monitors the track ahead and may stop the train in case of imminent danger. Acceleration and breaking are carried out automatically, as well as the supervision of the speed limit of the train. The operations staff is responsible for the safe departure of the train from the station. The safe closing of the doors may be entrusted to the operations staff or done automatically [3].

Driverless train operation (GoA3) – for this grade of automation, there is no member of staff at the front of the

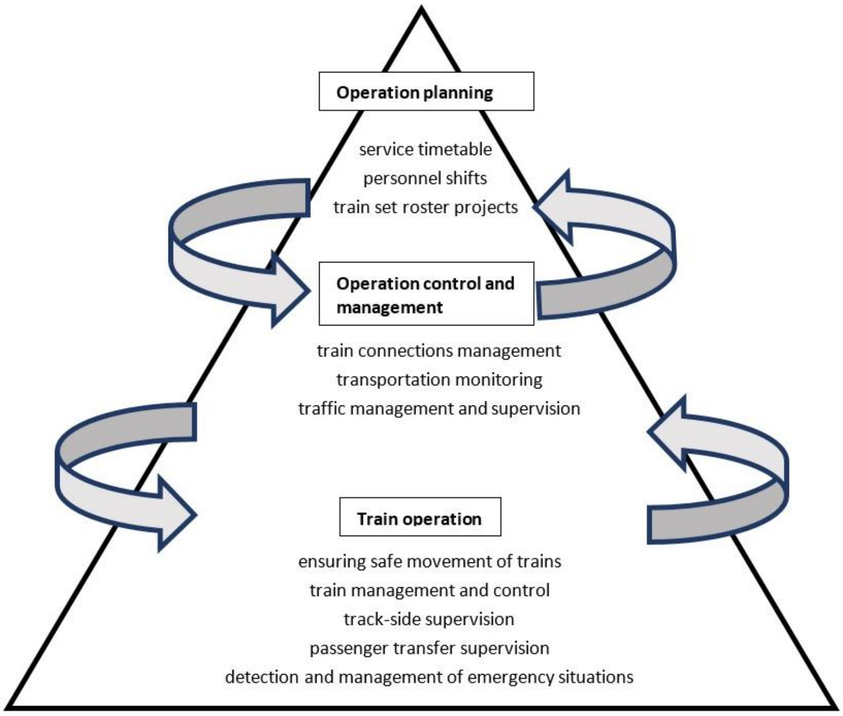
train to visually monitor the track and stop the train in case of danger. Safe movement of the train fully relies on the correct functioning of the protection equipment supervising the free passing and safety of the track. However, there must be operations staff on board the train to supervise the train itself. Depending on the optional functions of this grade of automation, the staff may be responsible for safe departure of the train, for closing the door, for the monitoring of the state of the train and safety of passengers. In particular, this member of staff is responsible for handling emergency situations during irregularities and system breakdowns, as the case may be [3].

Unattended train operation (GoA4) – at this grade of automation, further measures are required as opposed to GoA3, because there is no operations staff on board the train. The entire system must be equipped with safe detection equipment to report hazardous conditions and emergency situations. Whenever a hazardous situation requiring the intervention of operations staff occurs, such staff must be automatically informed and take remedial measures subsequently [3].

2.2. The Organization of Metro Operation

A basic hierarchy applies for urban guided transport operation, as well as for metros in general. This classification defines specific levels of operations organization, as shown in Fig. 1. Optional and mandatory system requirements are set for specific parts of the system, depending on the grade of automation. For all grades of automation, operations control is carried out from an Operations Control Centre (OCC)[1].

In case of automatic operation, it is necessary to clearly define the area covered by UGTMS control. The equipment needs to offer the possibility to check the train equipment at this area´s boundaries or within the area as such, in order to make information available about flawless functioning of the train-borne part of the equipment before putting the train into operation. This testing must be implemented in a way which does not require stopping the train when it is driving into or out of the area. In the UGTMS controlled area, all the functions depending on the given grade of automation, must be available. Train runs of trains not equipped with the train-borne part of the equipment are carried out alternatively and are governed by internal regulations of the railway manager [3].



Source: [4], edited by authors

Fig. 1 Metro operation organization scheme

For UGTMS systems, both automatic and manual positioning of directions of journey is admissible. Directions of journey are positioned with regard to the routing of the train or operational needs. In order to ensure a safe direction of journey, the authorisation for the movement of the train (movement authority) must be given only after the direction of journey is positioned and after the locking of the direction of journey. The unlocking of the direction of journey occurs automatically or manually after making sure that the whole train has moved past the relevant elements of the direction of journey [4].

The designated and operational intervals determined by the railway manager are another important safety element securing the safe movement of trains. The designated interval is given by the directional and height arrangement of

[1]OCC – Operations Control Centre

stations and tracks, by the periods of stalling, by traction properties of trains, arrangement of turning stations and the train operator´s reaction time (for grades of automation GoA0 – GoA2). The UGTMS system ensures the safe movement of trains in the network in the designated interval. Safe train separations can be ensured by fixed or flexible compartments. For each subsequent train, the absolute limit is set for the authorization of movement based on the position of the end of the preceding train [4].

Equipment at all grades of automation controls whether the safety speed limit is kept. Safety speed limits are determined based on the static and dynamic speed profiles. Dynamic speed profile is calculated based on the static speed profile and a safe braking model. The safe braking model must take into account variables such as inaccuracy in determining the position, the length of the train, the deviation of speed measurement, reaction time, reaction time of the emergency brake. A train moving in the controlled area must not exceed the dynamic speed profile, thus ensuring that the train shall not exceed the absolute limit for the authorisation of movement [4].

It is also possible to operate a train without the train-borne system equipment or with a non-functioning train-borne system equipment in the UGTMS-controlled area. However, under this reduced scheme, the UGTMS must ensure safety of operation with the lowest possible human factor dependency and while complying with traffic regulations [4].

2.3. Functionalities for Train Operation

The ensuing chapter covers basic functions relating to the train operation and its safe movement in the network operated in the automatic mode. The individual elements represent the cornerstones of the system safety.

Ensuring safe movement of the train. The positioning and securing of the requested direction of journey is fundamental for the safe movement of the train. The direction of journey must be locked and, subsequently, authorization for the train movement must be given. In terms of train operation, an essential requirement is ensuring the automatic identification of the position of the train when entering the area or when the train is activated on the operated network. Furthermore, the orientation of the train, i.e. the position of its front and rear part, must be ascertained. If this information is not available due to system failure, operation needs to be stopped on the section in question by applying emergency braking of the endangered train. In these cases, the system automatically creates a protective section where no trains can be allowed. The train may also be localised using a back-up system (if one is set up), in which case the movement of the train is organised in fixed sections of the area, where an absolute block condition must be met in order to secure the availability of each given section. If there is no available UGTMS functionality and there is no other technical equipment available to ensure the availability and correct positioning of the direction of journey, traffic needs to be organised pursuant to traffic regulations of the railway manager. The system must still be able to detect unauthorized movement of the train (e.g. unwanted autonomous movement of the train). Should any such event occur, the system must activate the emergency brake of the affected train without delay [4].

Train operation. Automatic trains are operated using driving speed profile. This profile is created with regard to the travelling culture and the energy load requirements and needs to be adapted to the dynamic speed profile in any case. Furthermore, the driving speed profile is based on data on infrastructure, vehicle parameters and critical operational parameters. Critical operational parameters refer to the stalling of trains in stations and on service tracks. The driving profile must change automatically when the input parameters of the calculation are altered [4]. For each train, the train route needs to be created, containing all the data on stopping of the train. However, this route can be changed based on operational needs and the driving profile needs to be adapted to this. The train must stop in all designated stations and there must be a possibility in place to keep it in the station based on the instructions of OCC staff [5].

Guideway supervision. The equipment on the track or on the vehicles must make sure that the train cannot collide with obstacles, i.e. with objects or persons in the clearance envelope. If the equipment detects an obstacle in the clearance envelope, a safety section must be created around this obstacle. The information also needs to be displayed in the OCC. Such a safety section may be called off only by a secure command given by the personnel after making sure that the track is clear. At the same time, if the train equipment detects an obstacle, the train needs to be stopped automatically and may be set in motion only after a secure command of the OCC service staff [3]. If the system is equipped with elements enabling the request for emergency stop by passengers or operations staff, the stations need to be fitted with equipment enabling emergency stop activation. Apart from the stopping of the train, a safety section is also created until it is securely called of by OCC staff [2]. Supervision over platform rails may be carried out using sensors detecting an obstacle on the track. However, in most cases, platform screens are used for AUGT system. In such a case, the closure and securing if the platform screen door needs to be controlled to enable safe entrance of the train to the station. If there is any interference with the system and an unauthorized opening of a door (including doors not intended for passengers), the train entering the area must be stopped and a safety section must be created. Such a section my only be called off by a secure command from the OCC [5].

In case infrastructure maintenance or other works are under way on the operated track, the system must enable the creation of a safe working section. This working section is inserted into the system manually by an OCC staff member who is also authorised to call off this working section after the track is cleared. Entry of the train into the working section may only be allowed by a secure command from the OCC issued individually in each case [4].

Supervising passenger transfer. As a minimum, passenger transfer supervision requirement must be met during the boarding and alighting of passengers, which represents the greatest risk to safety. Safety conditions must be met to ensure a safe boarding and alighting of passengers. The basic prerequisite is making sure that the train is securely stopped and secured in the designated place. Furthermore, the doors must be opened only on the desired side of the train. If the

system is equipped with platform screen doors, it is necessary to ensure that these open only after the train safely stops and is secured. If the train is shorter than the platform, only the platform doors enabling to board the vehicle must be opened. The closing of the doors shall be governed by a designated timetable or based on minimum designated time of stay of the train in the station [6].

As soon as the time of departure comes, the system sends a command to close the doors. Such closing of the doors may be accompanied by acoustic or visual signals. The closing of the door of the train and platform screen doors must be synchronised so as to ensure safe boarding and alighting of all passengers. If the security measures are ensured by detection elements, any intrusion of a person into the safe zone must not be indicated [4].

If the doors are closed and there is no requirement preventing the departure of the train, the train may leave the station at a time given by the train timetable. For grade of automation GoA3, the command for departure may be given directly by operations staff member, for GoA4, this command is given automatically [2].

2.4. Functionalities Serving Traffic Operation and Supervision

System functions necessary for a safe and smooth automatic operation of railway and rail transport represent another important feature of the automatic operation. For traffic operation, it is necessary to ensure that the OCC staff can keep track of all the decisive functions of the system.

Train lines management. UGTMS systems, depending on the grade of automation, require functionalities for the management of individual train lines to meet the projected transport demand. The system must be designed so as to minimize deviations from normal operation even in case of operational irregularities. For grades of automation GoA3 and GoA4, it is necessary to implement the function of systemic train route creation in compliance with train timetables and the correct assignment of the route to a specific train connection depending on its features. Specific assignment of the train connection to a train route may be carried out manually at the OCC or automatically. Each train with an assigned route must have a unique identification number. The system must enable manual adjustment of all parameters of the route, if need be [4]. Each route consists of a set of directions of journey. These directions of journey are positioned fully automatically in case of automatic operation. However, the OCC service staff must always be able to position a direction of journey manually. The direction of journey must be positioned well ahead of time to prevent the intrusion of the route by other trains and ensuing delays. The positioning of the direction of journey is triggered by the system based on data contained in the train route. The internal logic of the system must prevent positioning any direction of journey which would cause mutual blocking of trains. In case of unavailability of a selected direction of journey, the train run must be sorted out by a diversion [7].

Supervising rail transport operation. The system must enable continuous supervision of all trains in the operated area and it must be able to pass on information to service staff. Information on the position of communicating trains is essential. When using the alternative management system using track sections, the system must be able to provide information on the occupancy of these sections by a non-communicating train. UGTMS must keep automatic transport documentation on rail transport management. All train-borne and track-side signalling equipment whose function influences the safety and smoothness of rail transport operation must be supervised by the system and their immediate status must be detected. Information on failures and irregularities must be preferentially communicated to the HMI operation. When communicating the information, its importance needs to be determined so as to show information with higher level of priority first [4].

Functionalities for HMI interface. The system must ensure safe communication between the operation in the managed area and the OCC. The OCC staff must keep track of the status of all elements involved in the UGTMS system which are directly linked to the safety and smoothness of operation. Only locally controlled functions pertaining to system maintenance may be left out of this overview. The system must be able to work safely and pass on all the commands issued by the management staff at the OCC [4].

Passenger information systems and passenger supervision. The UGTMS system may be equipped with voice or audio-visual information system. In order to secure the passenger safety, the system must enable a voice call between passengers and the OCC staff during emergency communication devices (in the train, at the platform). If UGTMS is connected to the external passenger monitoring system, this system must be equipped so as to be able to show the video camera image from the location in question at the OCC in case a dangerous situation is detected [6].

3. The Possibilities of Introducing Automatic Operation at Metro Line B

Introducing automatic operation on a track which is already in operation is a complicated issue. It is a strategic decision requiring a comprehensive change of the organization of operation management. A detailed decision-making analysis needs to be drawn up, assessing all the benefits and drawbacks of the modernization of the signalling equipment. Furthermore, a risk analysis needs to be drawn up, assessing all the risks ensuing from the change of the grade of automation and the related transfer of a portion of responsibility from operations staff to a technical equipment.

Line B is currently equipped with track circuits and the ARS train signalling equipment, continuously controlling the speed of the train. It therefore follows that Line B is fitted with equipment meeting the criteria for the grade of automation GoA1. The transfer to automatic operation would require major adaptations of the station, track and train signalling equipment. At the same time, the operator´s control centre would need adjusting so as to be able to keep track of all the functions required for automatic operation.

The advantages and disadvantages of the transfer to automatic operation. The transfer to the automatic operation of trains on line B would require many changes of the current operation concept. Nevertheless, this seems to be an interesting alternative during the transfer to a completely new system. It is possible to go for the combination titled GoA2+ in the article. This presumes the operation of the existing train sets with train operators under ATO supervision and there is also the possibility of using the CBTC technology in combination with specific segments of ECTS which is available in the Czech Republic in terms of technology. This intermediate stage combines the advantages of modern signalling equipment (ETCS L3 moving block) and the current technology (train operator vs. safety screen doors at the stations). The use of ETCS would allow for the shortening of operation intervals and, most importantly, the minimum interval. This has a direct impact on the capacity of the whole metro system, which is already operating at the borderline of its operational capacity. However, this modification does not cover other related parts of the metro system, such as the platform capacity, escalators, ticket stamping machines etc. This would require a separate solution, which needs to be directly related to the modifications of metro operation. The simulation model based on the queueing theory can be useful in this situation. Table 2 gives an overview of the advantage and disadvantages of making use of the GoA2+ intermediate stage.

This system envisages the use of the existing infrastructure combined with train sets supervision using ETCS L3 (moving track sections). The ascertaining of parameters regarding the possibility to increase transport capacity and minimize operational intervals can be done by simulation. The simulation has been carried out but is not included in this article.

Table 2

Transfer to GoA2+

Advantages	Disadvantages
• improvement of operation safety by excluding or mitigating the risks of human failure • increased system flexibility, • improved travelling convenience, • the possibility to increase transport capacity	• investment costs • the necessity to carry out changes of operational regulations of the railway manager.

Source: authors

Table 3 compares the advantages and disadvantages of transfer to the fully automated operation GoA4.

Table 3

Transfer to GoA4

Advantages	Disadvantages
• improved punctuality of train connections, • improvement of operation safety by excluding or mitigating the risks of human failure • increased system flexibility, • improved travelling convenience, • the possibility to increase transport capacity, • minimization of operational intervals, • reduction of traction energy consumption, • fewer operations staff	• track investment costs, • station investment costs, • the necessity to modernize technical equipment of the track and train, • complications while ensuring normal operation during the intermediate stage, • the necessity to change legal regulations (Act on Railways), • the necessity to change of operational regulations of the railway manager

Source: authors

Requirements regarding the transfer to automatic operation. The basic prerequisite of the transfer to automatic operation is the reliable replacement of the role of the train operator or other operations staff by technical equipment. At the GoA1 grade of automation, the technical equipment is limited to signalling equipment controlling the safety and availability of the guideway, the ascertaining of the safe speed and safe train separation. However, the operations staff is responsible for the safe train guidance, train operation, passenger movement supervision and response to emergency situations. The change to the GoA4 grade of automation means the transfer of these functionalities to a technical equipment.

The existing technical equipment may also be used for the positioning of the directions of journey and secondary detection of the availability and integrity of track. However, the existing technical equipment needs to be integrated into the UGTMS system. Other automatic operation functionalities need to be ensured by a brand new technical equipment. The technical equipment must include functionalities for driving the train, for its safe acceleration and braking, as well as functions for monitoring the availability and free passing of the train track. In terms of passenger safety, functions ensuring the safe movement of passengers are essential. These are functionalities ensuring safe opening and closing of doors and devices, detection of the fall of passengers between train cars and platform and functionalities giving authorization to the train to leave the station only after the passengers have safely boarded and alighted. With regard to train operation, its automatic putting into and taking out of service needs to be ensured, as well as continuous review of the condition of trains and all their functional technical units indispensable for the safety and smoothness of operation.

With regard to the overall safety of operation, functionalities ensuring secure detection of any dangerous situation are vital. Depending on the nature of the situation, the system must enable a remote solution by the OCC or, as a minimum, communicating the information about the necessity of operations staff intervention. A detailed overview of functions for automatic operation is given in chapter 2.3.

Description of the transfer process regarding the introduction of automatic operation. Line B is one of the principal lines of Prague public transport. This implies that its taking out of service during the transfer to the automatic operation would bring about various challenges for the whole transportation system. There are three essential options regarding the solution of the intermediate stage during the modernization of the existing track [3]:

1) complete shutdown of the existing track and its re-opening only after the finalisation of its conversion;

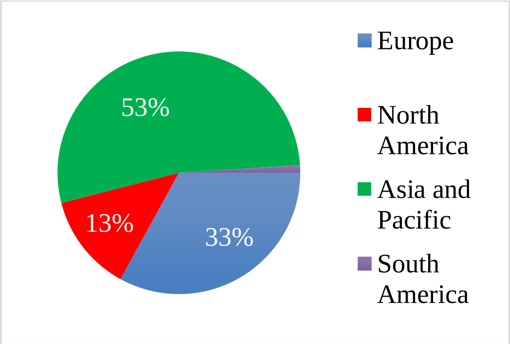
2) the continuation of operation for passengers using the existing equipment while working on the new equipment. Test runs would be carried out outside operation hours or in areas excluded from passenger transport operation;

3) the continuation of operation for passengers using the existing equipment while working on the new equipment. Test runs would be carried out during operation in a way which would reduce the scope of operation as little as possible (for example, during train breaks).

The work schedule and the conditions for the transfer process must be approved by the supplier of the equipment, the railway manager and the authority in charge of safety issues (*the Office for Railways*). Under no circumstances shall the train operation for passengers be put at risk by the test runs of trains operated automatically prior to their final approval. For these reasons, a risk analysis needs to be carried out including all the potential hazardous situations which might occur during the transformation process. At the same time, the work responsibilities of the operations staff need to be specified for each step of the transformation process. At the same time, the operations staff may be entrusted with interim safety measures applicable only for selected phases of the transformation process.

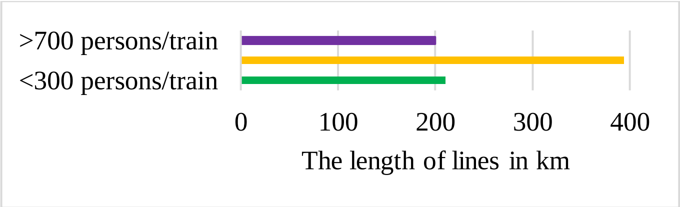
4. Automatic Metro Operation Systems Worldwide

The automation of high-speed railways has been an indisputable trend worldwide. In view of this, this chapter is dedicated to the metro automation trend around the world, including specific cases of application. The chapter goes on to describe particular automatic metro operations, stressing essential track parameters, signalling equipment and operated train sets. In June 2016, a total of 55 automated metro lines were in operation in 37 cities worldwide. A total of 157 cities have their own metro network, which implies that at least one automatically operated metro line can be found in 23% of cities with metro operation. The overall length of automatically operated metro tracks is 803 km, being14.2% longer than in 2014. According to existing projects, 2300 km of automated metro tracks will have been built by 2025. As shown in Fig. 2 below, Northern America, Europe and South-East Asia enjoy.



Source: [8] edited by authors

Fig. 2 Shares of the length of automatically operated metro lines worldwide



Source: [8] edited by authors

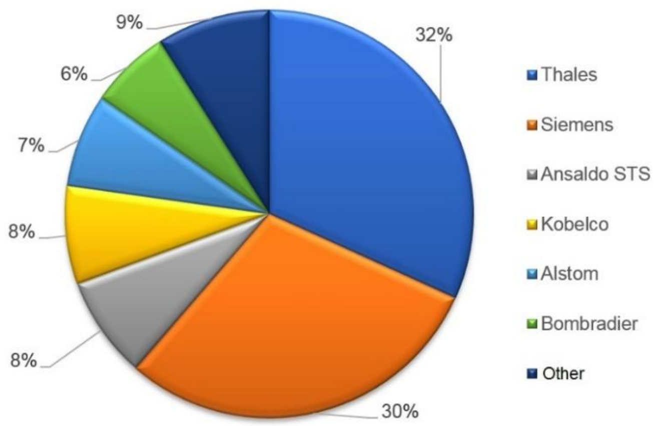
Fig. 3 Lengths of lines sorted by train set capacity

Countries with major shares of automatically operated lines include France, South Korea, Singapore and United Arab Emirates. Cities with the greatest lengths of automatic metro lines include: Singapore (93 km), Dubai (80 km) and Vancouver (63 km) [8]. Automatic operation was first tested on metro tracks with the capacity of one train for under 300 persons. The first automatically operated metro was opened in Lille, France in 1983 [9]. The shares of different metro lines sorted by train set capacity is shown in Fig. 3.

More than 30 years after the commissioning of the first line of automatically operated metro, the past decade has seen a significant growth of the share of automatically operated metro lines worldwide. Europe and Central and South-East Asia have enjoyed the most significant advancement of this technology. The greatest number of automatically operated metro projects are currently being developed in China. Further on, this chapter covers several specific European automatically operated metro lines on which enough relevant sources of information can be found, enabling their detailed description. The greatest emphasis is put on operational indicators, deployed vehicles and types of signalling equipment.

5. Signalling Equipment for Automatically Operated Metro

Currently, the CBTC type signalling equipment is the most widely used equipment for automatic metro operation, securing about 68% of the total length of automatic metro lines worldwide. The most important CBTC supplier is the company Thales, closely followed by Siemens [8]. The share of individual CBTC producers according to the length of lines they supplied with signalling equipment is shown in the graph in Fig. 4.



Source: [8], edited by authors

Fig. 4 The share of CBTC producers per length of lines

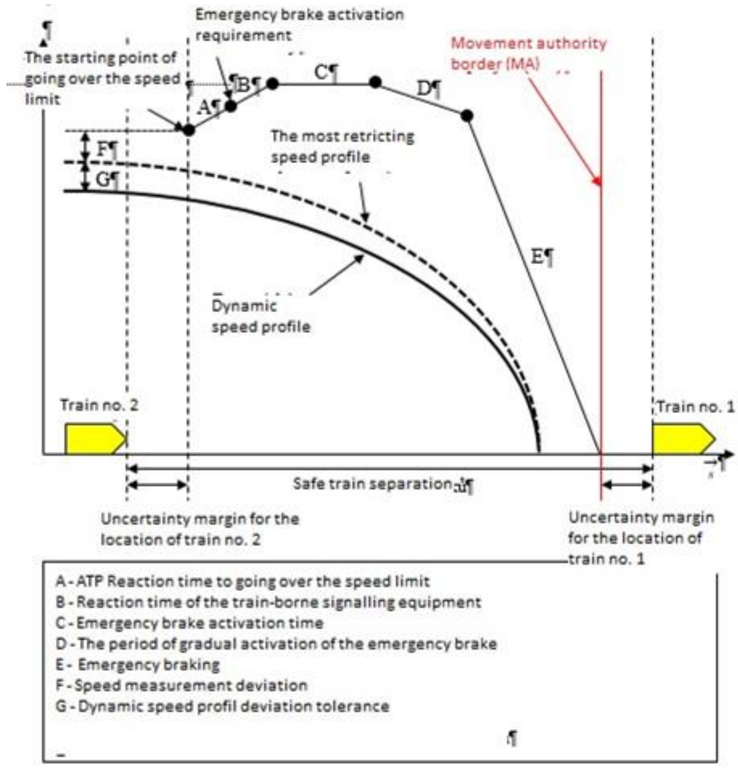
The CBTC equipment was developed primarily for high-capacity rail transport. This equipment is well suited for segregated tracks being used by trains with identical or very similar parameters and for tracks with a low risk of the endangering of transport by external influences (e.g. weather conditions, unauthorized movement of persons etc.) It follows from the above that the tracks suited for CBTC implementation include metro lines, or, as the case may be, tracks of other segregated urban and suburban lines. The CBTC system differs from the conventional signalling systems mainly by the possibility to operate trains in moving track sections. Conventional signalling systems use the signalling system with track-side or train-borne signalling devices for transport management and the track circuits or axle counter equipment is used for the detection of the position of the train. This is why they do not provide the possibility of operation in moving track sections, but only in fixed track sections marked by signalling devices or individual track sections. The CBTC system sorts this problem out by direct communication between the train-borne and track-side part of the signalling device.

The on-board part of the CBTC is able to determine the precise location of the train on the track with high precision and provide detailed data on the status of the train at the same time. This is how the CBTC systems can enable operation in moving track sections, thus reducing the distance between subsequent trains on the track. In these systems, the distance between subsequent tracks is determined as per the position of the end of the preceding train, the braking distance of the subsequent train and a safety margin. For the distance calculated this way, the system grants a so called *movement authority* [10]. A general diagram for determining the distance between subsequent trains is shown in Fig. 5.

The CBTC control system always provides accurate information on the position and speed of the train. Based on this information, the onboard part of the signalling equipment calculates the dynamic speed profile in order to ensure safe train separation. The specific part of the signalling equipment responsible for calculating this curve and for making sure that the train does not exceed the calculated speed curve is called the automatic train protection (ATP) [10]. With regard to system architecture, CBTC systems can be classified into two principal parts: the mobile part placed on the train, and the track-side part placed on the track and in the stations. The CBTC system must control the condition of the train exactly like a human train operator would, and, moreover, it controls train integrity and its exact location on the track. This activity is ensured by the automatic train protection (ATP) subsystem together with automatic train operation (ATO) subsystem and automatic train supervision (ATS) subsystem. The ATS subsystem controls all the trains in the network, controls the compliance with speed limits and timetables, as well as the functioning of information systems.

The CBTC system may also control the functions of other related systems, such as the function of track circuits, traction equipment and other infrastructure elements [10]. The CBTC system may function using two different mutual data transmission systems to transmitting date between the train and track-side part of the signalling equipment. The first option is the implementation of a radio network or inductive loops along the entire track. The other, more economic option

is placing communication elements continuously monitoring train operation at isolated points along the track [11]. Mutual communication of individual trains is another feature provided by CBTC. This means that the safe separation of trains is optimised using operational information exchanged between individual trains. The underlying principle here is guiding the train set onto a non-conflicting route, similarly to GTN. Information on train delay and its current speed and the scope of movement authority is also passed onto the subsequent train which can optimize its speed accordingly. This effect is further strengthened by using the moving block. Literature available on this subject covers this principle in greater detail [12].



Source: [11], edited by authors

Fig. 5 Diagram showing the process of determining a safe train separation

International CBTC system standards. Two basic international standards are defined for CBTC system. The first one is *Institute of Electrical and Electronics Engineers (IEEE) 1474.1* standard, the second one is the *IEC 62290*. IEEE 1474.1 was adopted in 2004. It regulates the functional and performance requirements for CBTC systems. In particular, the standard covers the train signalling equipment a such, id est the ATP subsystem. The ATO and ATS functionalities are defined as optional under this standard. The standard also sets out the principal safety requirements for the system. The standard does not cover only metro systems, but other rail transport systems, too.

Other IEEE standards regarding CBTC include the following: IEEE 1474.2 defining CBTC user interface, and IEEE 1474.3 and IEEE 1474.4, defining CBTC testing standards. The IEC 62290 standard was adopted in 2007. This standard sets out basic terminology, general requirements and the description of functionalities of the control and management CBTC subsystems. Speaking of CBTC, the relationship between the CBTC development and the ERTMS/ETCS also needs to be mentioned. These systems use a number of identical components and are governed by the same standards and system and safety requirements. Item on the literature list number 9 describes the CBTC function, adapted using ETCS L3 for simulation purposes. The development of ETCS components also enables their use in CBTC after partial adaptions. In the Czech Republic, the company AŽD Praha, s.r.o. is engaged in this development.

Basic components of the CBTC communication interface. Optical cables represent the basic fixed component of the communication network. These have sufficient capacity for the transmission of all necessary data. Cable design must be resistant to external influences, inter alia: fire resistance, resistance to humidity, resistance to acids and alkaloids, as well as mechanical resistance. In technical service rooms and cable exchange rooms, the cables must be sorted by their functional group. This measure is of particular importance in order to simplify the detection of failures and damage and to make maintenance easier [13].

The components of the radio network are another key component of the signalling equipment. The CBTC system implements the IEEE 802.11 a/g/p/n protocol (also used in common WiFi/WLAN networks). The greatest advantage is the fact that this is an open and widely used standard, which makes it possible to use various technical solutions for the radio network while maintaining mutual compatibility. The CBTC radio network functions with frequencies of 2.4 GHz or 5.8 GHz.

Both of these frequencies provide good characteristics and the range required for operation in metro tunnels [13]. In case the radio network is made using radio beacons positioned at specific points along the track, the system

communicates with the train using vehicle aerial. The train unit exchanges messages with the track-side part continually. If signal is lost or there is another failure (such as the incomprehensibility of the message), the train unit immediately commences high-speed braking. As with all signalling equipment, the communication branches are led along the entire track dually, where only one of these maybe active at any given time. Apart from the redundancy of individual components of the signalling equipment, these components are protected from the weather influences and mechanical damage. The track-side part of the signalling equipment consists of radio beacons positioned along the track within several dozens or even hundreds of meters of each other, covering all the locations of the track. The distance of the radio beacon is mainly influenced by local conditions, such as the directional guidance of the track and the tunnel parameters. Radio beacons may be mounted on separate posts or on other suitable track-side components. Radio beacons are interlinked using a dual optical fibre network. In addition to their high capacity, their principal advantage is their resistance to electromagnetism. The jumper connectors with a robust and durable design represent another important part of the communication network. Usually, class IP 67/68 is used.

The interconnected nodes of the communication network are usually placed in technical service rooms at stations. Apart from optical cable ports, radio beacons are fitted with a connection for electrical power for supplying their aerial. The radio beacon aerial must be resistant enough to external influences, such as: vibration, fire, shock waves, electrical discharge, humidity, changes in temperature and vandalism [8]. The train-borne part of the signalling equipment has redundancy of key elements, same as the track-side part. The aerials of the train-borne part of the signalling equipment may be dual and are connected to modems passing on or receiving data to or from the ATP. The ATP, including its cables, must be resistant to any assumed external influences [13].

6. Conclusion

The area of automatic train operation (ATO) is a modern trend in the field of rail transport. For the time being, it is mainly used in the field of urban underground railways. This article illustrates the options available for Prague metro in terms of automatic operation with regard to its expansion by line D. As part of the article, the possibility of transfer of the existing operation to automatic operation by adjusting of the signalling equipment and using new vehicle was considered. However, this option seems to be complicated and inefficient.

References

1. **Tischer, E.** 2016. Simulace automatického provozu na trase metra B (in Czech). Pardubice, Diploma work, University of Pardubice, 87 p.
2. ČSN EN 62267. Railway applications – Automated urban guided transport (AUGT) – Safety requirements). 2010. Praha: Czech Office for Standards, Metrology and Testing.
3. ČSN EN 62290 - 1. Railway applications – Urban guided transport management and command/control systems - Part 1: System principles and fundamental concepts), 2015. Praha: Czech Office for Standards, Metrology and Testing.
4. ČSN EN 62290 - 2. Railway applications – Urban guided transport management and command/control systems – Part 2: Functional requirements specification), 2015. Praha. Czech Office for Standards, Metrology and Testing.
5. **Gasparik, J.; Majercak, J.; Siroky, J.; Abramovic, B.; Mesko, P.; Nachtigall, P.; Zitricky, V.** 2017. Railway Traffic Operation. Žilina: Žilinská univerzita, 292 p.
6. **Široký, J.; Cempírek, V.; Gasparik, J.** 2014. Transport Technology and Control. Brno: Tribun EU, 238 p.
7. **Gasparik, J.; Siroky, J.; Peceny, L.; Halas, M**. 2014. Methodology for assessing the quality of rail connections on the network, In: Communications: scientific letters of the University of Zilina, 2: 25-30.
8. Statistics Brief: World report on metro automation - July 2016. In: UITP [online cit.: 2016-11-1]. Brusel: UITP, Available from: http://www.uitp.org/world-report-metroautomation
9. Lille VAL, France. In: Railway-technology.com [online cit.: 2016- 11-2]. Railway Technology. Available from: http://www.railway-technology.com/projects/lille_val/
10. Ferrari, A. 2014. Product Line Engineering Applied to CBTC Systems Development, In: Dipartimento di Ingegneria dell'Informazione [online cit.: 2016-11- 22]. Firenze. Available from: http://puma.isti.cnr.it/rmydownload.php?filename=cnr.isti/cnr.isti/2012- A2-043/2012-A2-043.pdf
11. **Chen, R.; Guo, J.** 2010 Development of the new CBTC system simulation and performance analysis [online cit.: 2017-05-20]. Southwest Jiaotong, School of Information Science & Technology, Southwest Jiaotong University, China. Available from: https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/114/21448
12. **Lindqvist, L.; Jadhav, R.** 2010. Application of communication based Moving Block systems on existing metro lines. In: Advanced Train Control Systems [online cit.: 2017-09- 18]. Beijing. Available from: https://books.google.cz/books?id=8e0fkqArGUYC&pg=PA44&lpg=PA44&dq=Advanced+Train+Control+Systems+with+press&source=bl&ots=w3k2QHKdNS&sig=kwaEpCNDQgGUc6F5M0HYW0GBkDA&hl=cs&sa=X&ved=0ahUKEwiJ_uqF5q7WAhXMQBQKHSZJDM4Q6AEIPzAE#v=onepage&q=Advanced%20Train%20Control%20Systems%20with%20press&f=false
13. CBTC Connectivity Solutions White paper. 2011. In: HUBER+SUHNER AG [online cit.: 2016-11-22]. Pfäffikon. Available from: http://www.railwaydirectory.net/company/feature/project_references/hash/a4c286bc338f 6eac9e60034c4152aba0/name/White%20Paper%20- %20CBTC%20Connectivity%20Solutions.pdf

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Recent Trends in Development of Safety Management Systems in Rail Transport

P. Smoczyński, A. Kadziński, A. Gill, A. Kobaszyńska-Twardowska

Poznan University of Technology, Pl. M. Skłodowskiej-Curie 5, 60-965 Poznań, Poland

Abstract

Research in the field of safety of technical systems, especially transport systems, has been focused on the analysis of the causes (sources) of so-called adverse events. This approach is consistent with the intuition and the forensic techniques of human reasoning, as well as successful in the study of simple systems. Still, it can be relatively difficult to use it for sociotechnical systems with complex structures. As a consequence, there is often a lack of full understanding of the processes within the systems, and this prevents them from being properly managed. However, new trends in safety research have emerged, such as functional resonance theory or the Safety-II concept. As part of them, the so-called Resilience Engineering has been proposed, postulating the transition from looking for the causes of adverse events to seeking the causes of correct implementation of system tasks. Changes in the manner of formulating safety rules are also suggested. The indicated evolution will probably soon cover also safety management systems. The article therefore describes the traditional approach to safety management and presents the foundations of resilience engineering as a recent trend in the development of safety management systems in rail transport.
KEY WORDS: *safety management systems, resilience engineering, Safety-II*

1. Introduction

Safety management in the intuitive form has been accompanying humanity since the beginning of time, because it is inseparable from the instinct of survival – requiring the abandonment of activities that are more likely to bring more harm than good. The need for a more formal approach to this subject, however, appeared only with the industrial revolution in the 18-th century [11] . It is possible to talk about safety engineering as a science from the beginning of the 20-th century, when Taylor started working on the so-called scientific management. The main goal of his research was to increase employee productivity by standardising the way the work was done, but at the same time it ensured a reduction in the number of accidents. The key book item devoted exclusively to the subject of safety is the work of Heinrich from the early 1930s [10], its edition from 1941 introduced the famous pyramid of types of adverse events. It is still reproduced in various safety-related studies (Fig. 1), although in reality serious accidents happen even after many years of work without any incident – for example, it was the case with the explosion on the Deepwater Horizon platform in 2010 [3].

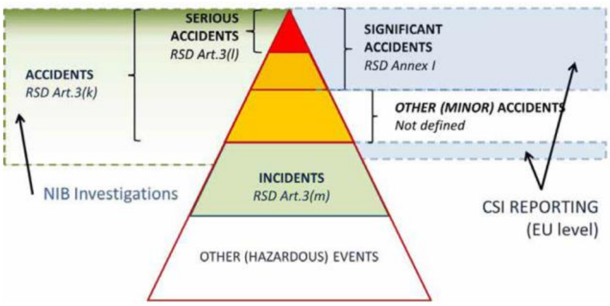


Fig. 1 Pyramid of adverse events introduced by Heinrich in 1941 in a contemporary report produced by the European Union Agency for Railways [6]

In the post-World War II period, reliability engineering developed, thanks to which many tools were introduced that are still in use today, such as FMEA and FTA. Along with the noticeable improvement of the reliability characteristics of technical facilities, more and more often adverse events resulted from errors of machine operators. As a consequence, the applied models have been supplemented by the so-called human factor. However, it did not take much time to conclude that the attempt to assign responsibility only to the operators of technical facilities does not bring the expected effect of reducing the number of adverse events and / or reducing their negative consequences. It became necessary to include in the analyses also the organizations in which these operators worked, which gave rise to safety management systems [11].

The results of scientific research have translated into legal regulations concerning security, in which since the 1970s there has been a move from concentrating on technical details towards establishing the methods of decision-

making and management [8]. This trend was additionally strengthened by the results of disasters from the 1970s and 1980s, such as the disaster on the Piper Alpha oil platform in 1988 [17] and the government's desire to withdraw from direct responsibility for the level of safety. Since the publication of the results of the Chernobyl disaster causes analysis in 1986, it is also said that it is necessary to strengthen the importance of the safety culture [19].

However, experience in implementing safety management systems has revealed a number of problems. Already in the 90s of the twentieth century, it was noticed that under the influence of ubiquitous procedures there are changes in the behaviour of people. Power [18] called this phenomenon the formation of an "audit society" in which a greater emphasis is placed on gaining another certificate than on the actual effects of work. Enforcing compliance with procedures has some positive effects, e.g. making collaboration more predictable [15], but also leads to the marginalization of the importance of knowledge and experience of employees [2]. In the railways, safety management systems are legally required under the Railway Safety Directive [5]. Their introduction, however, is not always in line with the ideas of the scientific community [2,15].

The aim of the work is to identify and present new proposals that may affect the shape of safety management systems in rail transport in the near future. Chapter 2 presents the concept of Safety-II and existing definitions of Resilience Engineering. Chapter 3 presents selected scientific papers showing the implementation of those concepts. The conclusions from the paper were formulated in Chapter 4.

2. Safety-II and Resilience Engineering

Traditionally, safety is understood as the state of absence of hazards with unacceptable risk [16], although in many publications the term "safety" is not explicitly defined [11]. Such a "negative" approach to safety causes a number of problems, including:

– together with increasing the level of safety, it becomes more and more difficult to measure it, because there is nothing to measure; the risk decreases, the hazards "disappear" [12];

– as the risk decreases, the number of data that can be used to improve the level of safety, such as the results of analyses of the causes of the decreasing number of adverse events, is reduced.

These issues are particularly important in the case of complex socio-technical systems, because it is not possible to accurately understand and describe the operation of such systems. In principle, detailed analyses are performed only as a result of adverse events in order to determine their causes. This gives the misleading impression that the majority of adverse events are caused by non-compliance with existing procedures or specifications.

However, there are studies, according to which accidents are not preceded by violation of procedures, but by "normal work", which consists of small improvisations or informal ways of dealing with frequently occurring, but insignificant problems [4]. Emphasizing the importance of "normal work", i.e. *work-as-done* in opposition to *work-as-imagined* is the basic postulate of a new approach to safety, called Safety-II. According to it, to increase the level of safety it is necessary not only to focus on reducing the identified or hypothetical causes of adverse events, but also to include increasing the resilience of systems. The term "resilience" is understood in four ways in literature [20]:

1. As rebound; the way of returning the system to the state before being forced;
2. As robustness; increasing the catalogue of extortions for which the system is prepared;
3. As graceful extensibility; the way I; which the system expands its operation or uses additional resources to adapt in case of unforeseen events,
4. As sustained adaptability; the policy allowing to continue proper functioning in the long term, under changing external conditions.

Sometimes it is considered [20] that only the last two approaches are justified. The study of the process of returning to the initial state is considered incomplete, because its course is determined by actions taken before extortion (which corresponds to increasing the resilience in terms of methods 3 and 4). Preparing the system for anticipated events is the same as the phase of reacting to the risk in the classical approach to the risk management process. An in-depth analysis of the various definitions of resilience can also be found in paper [1].

3. New Proposals for Safety Management Systems in Rail Transport

Works developing the concept of Safety-II and Resilience Engineering often try to propose certain models or solutions referring them to traditional solutions. This is noticeable in the description of socio-technical systems, for which Hollnagel [13] proposes the use of modelling which is based not on structures, but on functions. Individual functions can then be implemented both by technical elements and by people acting in accordance with their procedures. The visibility of the connection between people and technology allows for easier description of non-linear work of such complex systems, which by definition cannot be completely defined. An example may be the train speed reduction function, the implementation of which depends on various factors:

– technical, e.g. condition and temperature of the brake discs,

– organisational, e.g. the time of travel between successive stations or stops foreseen in the timetable,

– external, e.g. rainfall or the presence of leaves on the tracks.

The driver, taking into account mentioned factors, chooses the most appropriate way to implement the vehicle braking. Importantly, this method is often able to minimize the negative effects of technical equipment failures (e.g., a system preventing blockages of wheelsets) or their maladjustment to an unexpected situation.

Modelling of socio-technical systems through in terms of functions is also used in the functional resonance analysis method (FRAM). Functional resonance is the situation in which the negative implementation of many functions overlaps in such a way that the limit of unacceptable performance is exceeded. This is schematically shown in Fig. 2. Searching for the causes of adverse events using FRAM is not limited to showing non-compliance with a specific procedure, but it is about understanding the interactions between various functions of the analysed system.

Fig. 2 Schematic representation of adverse events as a result of the superposition of functions exceeding the limit of unacceptable performance [12]

The employees' resilient reaction is influenced by the way in which the procedures applicable to them are developed. Hale and Boris [9] described two models of safety procedure management. Model No. 1 is rooted in Taylor's scientific management and provides for a thorough description of the activities to be performed by employees. Once developed, the procedure usually should not be changed, and any non-compliance by employees is considered to be their insubordination and punished. This approach makes the development of procedures relatively easy, they are understandable for beginners and organise the flow of work. Model No. 2 provides for an active role of employees in the development of procedures that should primarily reflect the actual way of performing activities, and not – their idealized image. In case of violation of procedures developed according to model No. 2 it should be checked if it is not reasonable to change the content of procedures and only then should any possible disciplinary consequences for employees be drawn. Despite some negative features of the Model No. 2, described in more detail in the paper [9], it is indicated as an important alternative to the more common Model No. 1, which often leads to excessive bureaucracy and the emergence of differences between the work assumed in procedures and actually performed by employees.

Some tips on formulating procedures in a way that stimulates system resilience can be found in the paper of Grote [7]. Is states that increasing the flexibility of the organization and the related uncertainty may lead to an increase of the level of safety, as people who are not bound by rigid procedures may be more able to adapt their behaviour to unexpected conditions. In this context, classification based on the work of Reason and Rassmusen can be used, according to which the procedures can be divided into three groups:

- action rules, defining how to perform a given activity
- process rules, in which the method of making decisions on performing activities is defined (e.g. by the means of risk assessment or consultation)
- goal rules, specifying only the objectives to be achieved; all possible means are equally eligible.

It can be assumed based on paper [7] that action rules should be used in situations where repeatability of a given process is important. In the railway context, such processes are in principle all processes related to train traffic, railway signalling, or communication methods between train drivers and traffic dispatchers. Process and goal rules, on the other hand, allow for greater freedom in choosing the way of action, increasing flexibility. They can be and are used in situations not provided for in the timetable, such as making the connecting train wait in case of a delay.

An extreme approach to the subject of procedures, perhaps too far-reaching for railway applications, is the complete elimination of all safety procedures. This was the subject of research described by Dekker at work [3]. In a group of stores belonging to one of the American retail chains, it was decided to leave only those procedures that were explicitly required by law (e.g. escape routes), and a general rule: do not harm others. The employees virtually immediately resigned from many previously ordered activities, above all – bureaucratic ones. They also undertook more initiatives to ensure an adequate level of safety and were more assertive in their enforcement from their superiors (e.g. the exchange of uncomfortable tools). Taking responsibility for one's own safety (i.e. the state of functioning in the absence of hazards with unacceptable risk) along with informing employees about possible ways of using this responsibility gave, in the opinion of the authors of the experiment, the best results in increasing the level of safety.

4. Conclusions

The concept of resilience opens many lines of research in the EU railway system, which may contribute to a better understanding of the conditions for generating adverse events in it. In particular, these trends can be reduced to:

1. Acquisition of knowledge about the proper functioning of the railway system components despite exposure to hazard sources.
2. Discovering the processes and mechanisms conditioning the successful operation of safety systems established in the railway system.
3. Promoting the concept / idea of resilience in the railway system through early activities of avoiding some hazard sources and appointing appropriate elements of safety systems.
4. Transferring to the railway system good practices developed while applying the concept / idea of resilience in other areas of human activity.

Acknowledgements

The research work financed with the means of statutory activities of Faculty of Machines and Transport, Poznan University of Technology, 05/52/DSPB/0280.

References

1. **Adjetey-Bahun, K.; Birregah, B.; Châtelet, E.; Planchet, J.-L.** 2016. A model to quantify the resilience of mass railway transportation systems, Reliability Engineering & System Safety 153: 1-14, Doi: 10.1016/j.ress.2016.03.015.
2. **Almklov, P.G.; Rosness, R.; Størkersen, K.** 2014. When safety science meets the practitioners: Does safety science contribute to marginalization of practical knowledge? Safety Science 67: 25-36. Doi: 10.1016/j.ssci.2013.08.025.
3. **Dekker, S.** 2018. The safety anarchist: relying on human expertise and innovation, reducing bureaucracy and compliance. New York: Routledge.
4. **Dekker, S.W.A.** 2014. The bureaucratization of safety, Safety Science 70: 348-57, Doi: 10.1016/j.ssci.2014.07.015.
5. European Parliament and Council. 2016. Directive (EU) 2016/798 of 11 May 2016 on railway safety (recast).
6. European Union Agency for Railways. 2016. Railway Safety Performance in the European Union.
7. **Grote, G.** 2015. Promoting safety by increasing uncertainty – Implications for risk management. Safety Science 71: 71-79, Doi: 10.1016/j.ssci.2014.02.010.
8. **Hale, A.R.; Heming, B.H.J.; Carthey, J.; Kirwan, B.** 1997. Modelling of safety management systems. Safety Science 26(1–2): 121-140, Doi: 10.1016/S0925-7535(97)00034-9.
9. **Hale, A.; Borys, D.** 2013. Working to rule, or working safely? Part 1: A state of the art review. Safety Science 55: 207-221, Doi: 10.1016/j.ssci.2012.05.011.
10. **Heinrich, H.W.** 1931. Industrial Accident Prevention: A Scientific Approach.
11. **Hollnagel, E.** 2014. Safety-I and safety-II : the past and future of safety management. CRC Press.
12. **Hollnagel, E.** 2018. Safety-II in Practice. Routledge.
13. **Hollnagel, E.** 2008. Critical information infrastructures: Should models represent structures or functions? Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 5219 LNCS: 1–4, Doi: 10.1007/978-3-540-87698-4_1.
14. **Hollnagel, E.** 2012. FRAM, the functional resonance analysis method: modelling complex socio-technical systems. Ashgate.
15. **Jeffcott, S., Pidgeon, N., Weyman, A., Walls, J.** 2006. Risk, trust, and safety culture in U.K. train operating companies, Risk Analysis 26(5): 1105-1121, Doi: 10.1111/j.1539-6924.2006.00819.x.
16. **Kadziński, A.** 2009. Integracja pojęć. In: Krystek, R., editor. Zintegrowany system bezpieczeństwa transportu. T. 2, Uwarunkowania rozwoju integracji systemów bezpieczeństwa transportu, Warszawa p. 285-289.
17. **Paté-Cornell, M.E.** 1993. Learning from the Piper Alpha Accident: A Postmortem Analysis of Technical and Organizational Factors, Risk Analysis 13(2): 215-232, Doi: 10.1111/j.1539-6924.1993.tb01071.x.
18. **Power, M.** 1997. The Audit Society. Rituals of Verification. Oxford: Oxford University Press.
19. **Wang, C.-H.; Liu, Y.-J.** 2012. Omnidirectional safety culture analysis and discussion for railway industry. Safety Science 50(5): 1196-1204, Doi: 10.1016/j.ssci.2011.12.031.
20. **Woods, D.D.** 2015. Four concepts for resilience and the implications for the future of resilience engineering. Reliability Engineering & System Safety 141: 5-9, Doi: 10.1016/j.ress.2015.03.018.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Safety of Citizens in Road Transport as a Factor of Quality of Life

V. Šoltés[1], J. Kubás[2], Z. Štofková[3]

[1]*University of Žilina, Univerzitná 8215/1, 01026 Žilina, Slovakia, E-mail: Viktor.Soltes@fbi.uniza.sk*
[2]*University of Žilina, Univerzitná 8215/1, 01026 Žilina, Slovakia, E-mail: Jozef.Kubas@fbi.uniza.sk*
[3]*University of Žilina, Univerzitná 8215/1, 01026 Žilina, Slovakia, E-mail: Zuzana.Stofkova@fpedas.uniza.sk*

Abstract

One of the State's task is to invest funds into the development of road infrastructure to attract new investors. The importance of road infrastructure is also increasing due to traveling to work, school, or during leisure activities. Through the development of road infrastructure, it is possible to reduce number of traffic accidents, unemployment, increase competitiveness, and thus increase the quality of life of population. With the development of road infrastructure, the road network is expanding, and the risk of traffic accidents is changing. With the accession to the European Union, the Slovak Republic has undertaken to reduce the number of traffic accidents caused on roads. Traffic accidents represent one of the greatest safety risks for road users. The paper deals with the analysis of traffic accidents of pedestrians and motor and non-motor vehicles in the individual regions of Slovakia. The aim of the paper is to point out the riskiest road users. The results can be used to increase the safety of the existing road network but also for planning further development of road infrastructure to improve the quality of life of citizens.
KEY WORDS: *transport, security, car accidents, protection of persons*

1. Introduction

There are many factors influencing the quality of life. The perception of quality of life is therefore highly subjective. Among the most important aspects that affect the quality of life belong socio-economic, geographical, environmental and security situation. The individual indicators through which mentioned situations can be objectively expressed vary depending on the territory to which they relate. The perception of quality of life therefore also dependent on the territory to which it relates. At present, the security situation is at the forefront of the quality of human life. Security situation can be objectively examined through security incidents. Such security incidents include, for example, the number of recorded criminal offenses and other anti-social activities or the number of recorded traffic accidents. In terms of security, the lack of road infrastructure and the likelihood of traffic accidents have the most negative impact on the quality of life of Slovaks.

2. Quality of Life

Understanding the quality of life is dealt with at different levels of different disciplines. It is possible to talk about quality of life in relation to psychology, medicine, ecology, politics, sociology, philosophy. The subject of quality of life research therefore varies depending on the need for a specific discipline or its level [1]. In general, quality of life is understood as consequence of the interaction of many different factors. These are the social, health, economic and environmental conditions that interact in a cumulative and very often unknown (or unthinkable) way, thus influencing human development at the level of individuals and entire societies [2].

Quality of life finding can be two-fold. The first way of identifying the quality of life can be called objectivist, as it focuses on "objective" indicators, predominantly economic. However, there are rather used indicators that are examined at the level of aggregate variables (e.g. at national, regional, local level) and afterwards they are extrapolated to the individual level. Therefore, its informative value about the actual quality of life of an individual is problematic, it remains only at the level of "average information". The second way to determine quality of life - subjectivist - is mainly used by psychologists. This approach focuses directly on the subjective information of the individual about his well-being and satisfaction [3].

The simplest one-dimensional indicator of quality of life is Gross Domestic Product (GDP), which reflects the market value of goods and services produced in the country before deducting consumption of fixed capital [4]. The well-known comprehensive indicators of quality of life include the Quality of Life Index (QoLI) introduced by the Economist Intelligence Unit and by the journal The Economist, and the Human Development Index (HDI) introduced by the United Nations Organization [5].

The Quality of Life Index (QoLI) consists of nine indicators, including an indicator of material well-being, health, political stability and security, family life, community life, climate and geography, job security, political freedom, and gender equality [6].

The Human Development Index (HDI) is a composite indicator that measures the average performance of the country in the three basic dimensions of human development:

1. a long and healthy life measured by the average life expectancy at birth;
2. knowledge mean of years of schooling for adults aged 25 years and more and expected years of schooling for children of school entering age;
3. level of living standard expressed in GDP per capita [7].

Quality of life according to the World Health Organization is also a comprehensive tool for measuring quality of life, but it differs from the previous two tools in that it is the assessment of indicators by individual [5]. The World Health Organization's tool assesses subjective well-being in six domains, that consists of several facets. Among the domains belongs physical domain, psychological domain, level of independence, social relationship, environment, and spirituality/religion/personal beliefs [8].

3. Road Infrastructure in Slovakia

Road transport is the most used type of transport in Slovakia. In the last decade, it has witnessed a significant boom in both the transport of goods and the carriage of persons. The total length of roads in 2017 was 18,057 kilometers, which is only 26 kilometers more than in the previous year. By the type of road communications, the can be divided into motorways, expressways, 1st class roads, 2nd class roads and 3rd class roads [9]. Figs. 1 and 2 show the development of the length of these types of roads over the last 10 years.

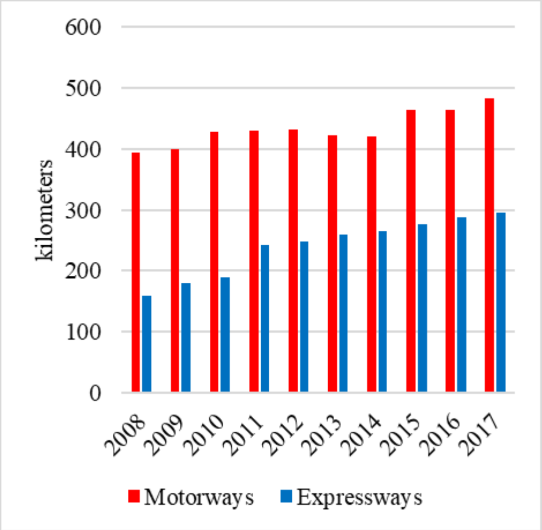


Fig. 1 Development of length of motorways and expressways in Slovakia [10]

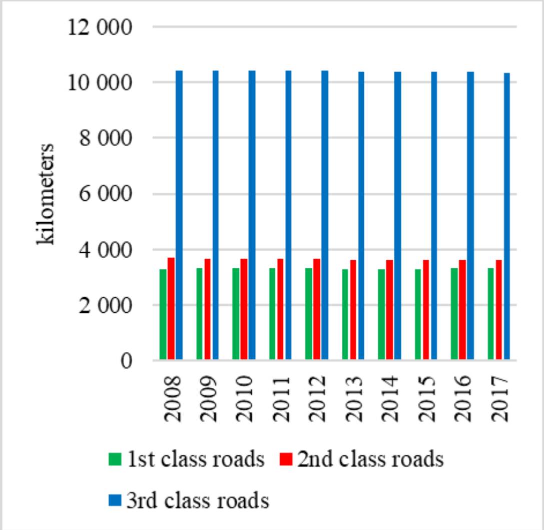


Fig. 2 Development of length of 1st class roads, 2nd class roads and 3rd class roads in Slovakia [10]

Road safety, and related traffic accidents on the road, which represents an important indicator of road conditions and traffic conditions, affects the level of transport performance of the society. Therefore, it is an important criterion in the planning, construction, renovation, and maintenance of the road network [11]. Motorization and of road transport has an ever-increasing tendency. Besides unquestionable advantages, they also bring with them a great increase in the load on the road network and increasingly demanding transport and security requirements [12].

Transport security is not only a serious transport, social, but also economical problem. Traffic accidents are associated with great material damage, permanent damage to the health of the population and very often with irreparable losses to human life [13]. That is why to road security and its individual factors (which are affecting it) are currently paying attention throughout the world and, of course, also in the European Union. By joining the European Union, the Slovak Republic has committed itself to achieving standards comparable to those of advanced Europe in all areas. Slovakia and other European Union countries have committed to halve the number of road deaths by 2020 compared to 2010. Back then, 345 people died in Slovakia [14].

4. Analysis of Traffic Accidents Caused by Motor and Non-Motor Vehicles and Pedestrians in Slovakia

In many cases, guilt for a traffic accident carries a human factor. Depending on the traffic accident, it is possible to divide them into traffic accidents caused by pedestrians, motor vehicles or non-motorized vehicles. Fig. 3 shows the development of traffic accidents caused by motor vehicles in individual regions of the Slovak Republic.

Traffic accidents caused by a motor vehicle represent about 95 percent of all traffic accidents. At the beginning of the observed period, the number of traffic accidents caused by a motor vehicle was nearly 23,000, down by around 10,000 in 2011, falling to 12,000 in the following year, and stabilizing. Regarding the regions, the most traffic accidents caused by a motor vehicle are recorded in the Bratislava region. In terms of size, this region is the smallest, but the traffic situation is quite complicated, as Bratislava is the capital of the Slovak Republic. Behind the Bratislava region are Prešov and Žilina regions. On the contrary, in the Trnava and Trenčín regions, in long term there are recorded least number of traffic accidents caused by a motor vehicle.

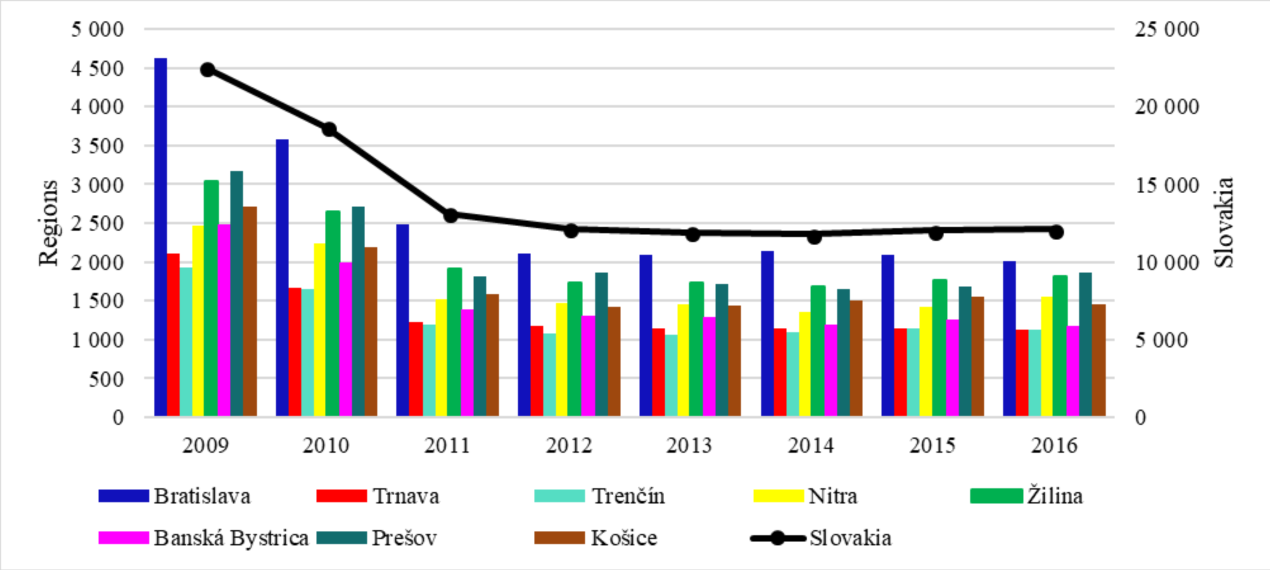


Fig. 3 Development of traffic accidents caused by motor vehicles in Slovakia [10]

Traffic accidents, however, may not only be caused by a motor vehicle. Fig. 4 shows the development of traffic accidents caused by non-motorized vehicles in individual regions of the Slovak Republic. As the non-motor vehicle can be considered as a trailer, a vehicle driven by human power or by an animal force.

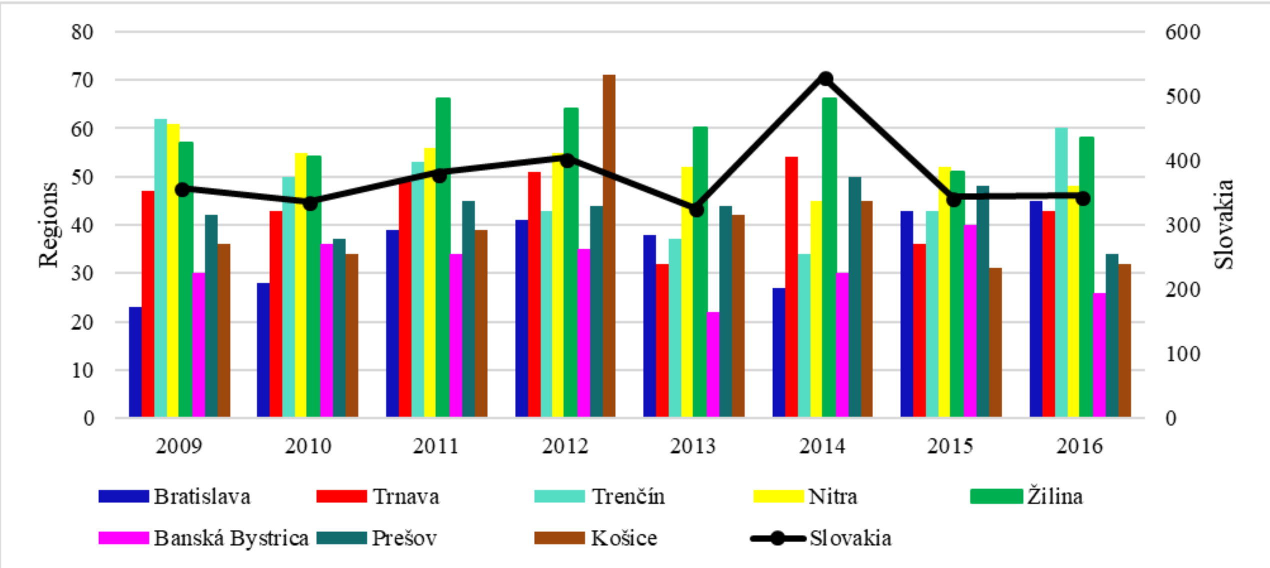


Fig. 4 Development of traffic accidents caused by non-motor vehicles in Slovakia [10]

The number of traffic accidents caused by a non-motorized vehicle represents approximately 1 - 3 percent of the total recorded traffic accidents. In the observed period, on average, 400 such accidents occurred on the territory of Slovakia. From the point of view of the development of the number of traffic accidents of this type, the situation in Slovakia is stabilized. The exception is only 2014, when more than 500 traffic accidents caused by a non-motor vehicle were recorded in Slovakia. While the situation in Slovakia is stabilized from this point of view, the situation in the regions is very dynamic. The most extreme is the Košice region, where the highest number of road accidents caused by a non-motor vehicle in the observed period was recorded in 2012. However, in the long term it can be possible to say that the worst situation is in the Žilina and Nitra regions. Conversely, least traffic accidents caused by a non-motorized vehicle are recorded in the Banská Bystrica region.

In addition to drivers of motor and non-motorized vehicles, pedestrians are also involved in road traffic. Fig. 5 shows the development of traffic accidents caused by pedestrians in individual regions of the Slovak Republic.

The number of traffic accidents caused by pedestrians is comparable to the number of traffic accidents caused by a non-motorized vehicle. At the beginning of the observed period, pedestrians caused approximately 700 traffic accidents. This number has fallen steadily above the 400 and in the last period it has been around 500 traffic accidents. Regarding the regions, pedestrians in Trnava, Trenčín and Nitra regions signed the least these types of traffic accidents. As a least secure region in the long term, the Bratislava, Košice and Prešov regions appears in this point of view.

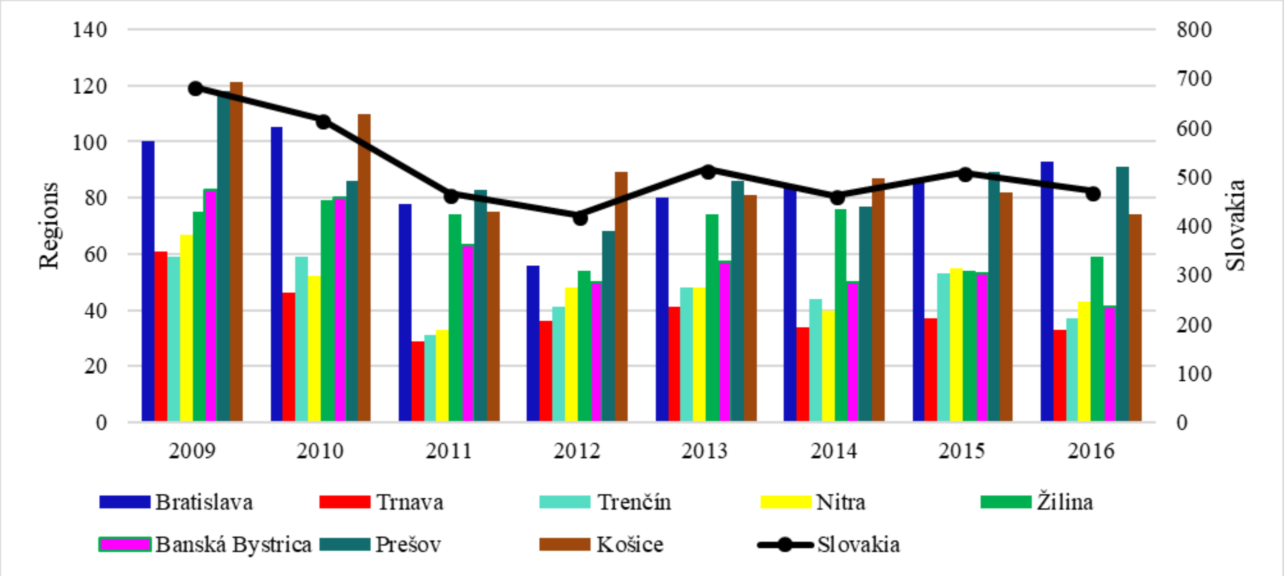


Fig. 5 Development of traffic accidents caused by pedestrians in Slovakia [10]

Fig. 6 shows the development of the total number of traffic accidents recorded in Slovakia in the observed period.

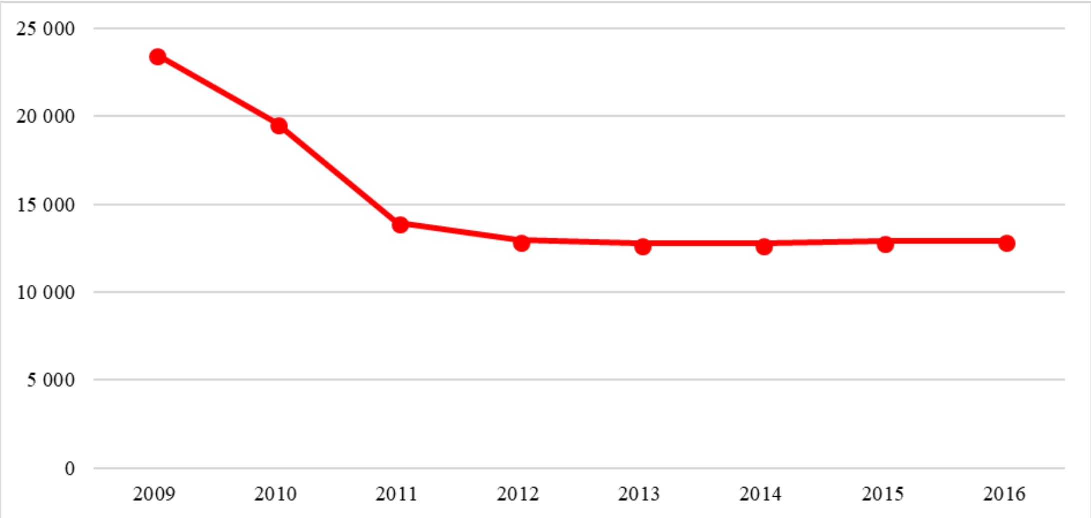


Fig. 6 Development of all traffic accidents in Slovakia [10]

As up to 95 percent of traffic accidents in Slovakia are caused by a motor vehicle, the development of the total number of traffic accidents strongly correlates with this type of traffic accident. The number of traffic accidents in Slovakia has decreased recently. While in 2009 there were almost 24,000 traffic accidents in Slovakia, a year later it was less than 20,000 and in 2011 the number of traffic accidents was below 14,000. Subsequently, this number of road accidents stabilized and in the last five years below under 13,000 traffic accidents. It should be noted that there has been a slight increase in traffic accidents over the past three years (about 100 traffic accidents per each year).

Stabilized road security is being maintained in Slovakia despite the increase in the number of cars and drivers. In 2017, up to 3,069,482 motor vehicles were registered in Slovakia (from 2007 the number increased by one million) and 3,504,985 drivers (with a population of approximately 5.4 million in Slovakia) [10].

Fatal traffic accidents in many cases also end up tragically with the victims on human life. The most frequent cause of fatal traffic accidents in Slovakia in 2017 was mostly not paying attention to driving [14]. As was already mentioned, member states of the European Union committed themselves to halving the number of road deaths by 2020 by 2020. According to the Annual Accident Report 2017 created by The European Commission, for the second consecutive year in the European Union member countries, roughly two-percent decrease in the number of road deaths occurs. In 2017, 25,300 people lose their lives on the roads of the member countries of the European Union, which is 300 less than in 2016 and 6,200 less than in 2010 (20 percent decrease). At the same time, The European Commission statistics indicated that European roads with the average of 49 deaths per million inhabitants were also the safest in the world in 2017. Sweden (25 deaths per million inhabitants), Britain (27), the Netherlands (31) and Denmark (32) showed the best results. Compared to 2016, Estonia recorded the largest drop in deaths (32 percent) and Slovenia (20 percent

less). Slovakia had 57 deaths per million inhabitants in 2017, a 12 percent increase over 2016; however, compared to 2010 there is a 13 percent decline in road deaths. In 2017, only Romania and Bulgaria reported a mortality rate of over 80 deaths on roads per million inhabitants [15].

5. Conclusions

Security is currently one of the most important aspects of quality of people’s life. Security can be expressed both subjectively and objectively through indicators (such as quality of life). The number of traffic accidents caused on road infrastructure is one of the security indicators that also greatly affects the quality of people’s life in the territory. Faulting human factor is one of the most common causes of a traffic accident. A traffic accident can then be caused by a motor and non-motor vehicle or by a pedestrian. At present, there are approximately 13,000 traffic accidents per year in Slovakia. Up to 95 percent of them was caused by a motor vehicle. The cause of these accidents is almost always not paying attention to driving. It is for this reason that the state has to use all means to make drivers aware of the serious consequences that may result from phone calls behind the steering wheel, writing text messages, or filming video on a mobile phone.

Acknowledgements

This paper was undertaken as part of the research project VEGA 1/0696/16 and VEGA 1/0755/18

References

1. **Šikula, M.** 2008. Dlhodobá vízia rozvoja slovenskej spoločnosti. Bratislava: Ekonomický ústav SAV, 274 p. (in Slovak).
2. **Payne, J. et al.** 2005. Kvalita života a zdraví. Prague: TRITON, 630 p. (in Czech).
3. **Mühlpachr, P.** 2005. Měření kvality života jako metodologická kategorie. Zborník príspevkov z vedeckej konferencie s medzinárodnou účasťou, Prešov: 59-71. Available from: http://www.jozefmiko.sk/06_vedecke_konferencie/00_zborniky_z_vedeckych_konferencii/10_zbornik_kz_a_rp_24_25_11_2004_presov.pdf (in Czech).
4. **Štofková, J.; Repková Štofková, K.; Kaštánek, P.** 2015. Finance. Bratislava: DOLIS, 152 p.
5. **Bianchi, G.** 2005. Is it possible to Measure Quality of Life? Životné prostredie, Bratislava 39(6): 285-289. (in Slovak).
6. The Economist Intelligence Unit's quality-of-life index [online cit.: 2018-06-22]. Available from: https://www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf
7. Human Development Index (HDI) [online cit.: 2018-06-22]. Available from: http://hdr.undp.org/en/content/human-development-index-hdi
8. WHO QoL Manual. [online cit.: 2018-06-20]. Available from: http://www.who.int/mental_health/evidence/who_qol_user_manual_98.pdf
9. **Šoltés, V.; Kubás, J.; Štofková, Z.** 2017. The impact of a transport safety situation on crime situation and quality of life. Proceedings of the 21th international scientific conference Transport means 2017, Juodkrante: 963-967.
10. Regional statistical yearbook of Slovakia 2017 [online cit.: 2018-06-20]. Available from: https://slovak.statistics.sk/PortalTraffic/fileServlet?Dokument=a69fb25e-6689-4a43-ab84-129cf4054462
11. **Gašová, K.; Repková Štofková, K.** 2017. E-Government as a quality improvement tool for citizens’ services. Procedia Engineering 192: 225-230.
12. Bezpečnosť cestnej premávky [online cit.: 2018-06-20]. Available from: http://www.ssc.sk/sk/cinnosti/rozvoj-cestnej-siete/bezpecnost-cestnej-premavky.ssc (in Slovak)
13. **Šoltés, V.; Repková Štofková, K.; Kubás, J.** 2016 Possibilities of using funds by local government for transport and communications. Proceedings of the 20th international scientific conference Transport Means 2016, Juodkrante: 546-500.
14. **Kubás, J.; Veľas, A.; Šiser, A.** 2017 Implementation of multi-criteria decision making as the method used to achieve optimal level of security in local municipalities. ICMIBI international conference on training, education and management, Dubai: 371-375.
15. Annual Accident Report 2017 [online cit.: 2018-06-22]. Available from: https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/statistics/dacota/asr2017.pdf

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Assessment of Noise Levels Caused by Passenger Wagons: a Case of Paneriai Railway Station

L. Sladkevičienė[1], E. Valma[1], K. Čižiūnienė[1,2]

[1]*Vilnius College of Technologies and Design, Antakalnio str. 54, 10303, Vilnius, Lithuania,*
E-mail: l.sladkeviciene@vtdko.lt; e.valma@vtdko.lt; k.ciziuniene@vtdko.lt
[2]*Vilnius Gediminas Technical University, Plytinės str. 10105, Vilnius, Lithuania, E-mail: kristina.ciziuniene@vgtu.lt*

Abstract

Rail transport is one of the dominant transport sectors that can is used to successfully carry large loads and passenger traffic over long distances. However, the noise caused by the train traffic creates a negative impact on the human body. This negative impact affects not only the railway workers, but also people living up to 100 meters from the railroad. Thus, this article presents the results of the survey that measured the noise created by passenger trains at Paneriai railway station in the evening. The study evaluated the climatic conditions, train types and the number of wagons in the block.
KEY WORDS: *railway transport, noise, measurements, Paneriai railway station*

1. Introduction

The negative impact of noise on health has been known since as early as ancient times. Noise is a subjective definition of a sound, which indicates that the sound is strong, unpleasant, unexpected, unwanted or harmful, it may cause adverse health effects; it is caused by people or their activities, including the use of vehicles, train traffic, road traffic, air traffic (transport and logistics – part of the global network).

Noise has become one of the most pressing environmental problems that afflicts both rural and urban populations. Noise is closely related to human activity, and there are a lot of noise sources. Rural residents are most vulnerable to noise caused by agricultural work and by equipment used in their living environment. Urban residents have the greatest negative impact by rail, road and airborne noise "[7].

The purpose of the research was to survey noise caused by passenger trains at Paneriai railway station.

The respective goals were twofold:

1. To conduct theoretical analysis of impact of noise, produced by railway activity.
2. To survey noise caused by passenger trains at Paneriai railway station.

2. Theoretical Analysis of Impact of Noise, Produced by Railway Activity

The level of noise is currently included in the national noise reduction law, the "Environmental Impact Assessment Report" states that "the noise management law establishes the authority responsible for the preparation of plans for noise prevention, the content of the noise prevention plan and the timetable for the preparation of plans. The purpose of this law is to regulate the activity in which the noise is emitted, to prevent hearing damage or loss, protect human life and health and the environment from the negative effects of noise.

The impact of vibrations, produced by rolling stock, on the health of people is an acute problem not only in Lithuania but also in the world. Vibration mitigation / mitigation measures, differently from noise prevention measures, are not specifically mentioned neither in Lithuanian nor in international practice,

Lithuanian Hygiene Norm HN 50: 2003 presents classification of vibrations that affect a human body, the regulated parameters and their maximum allowable sizes as well as measurement requirements in residential and public buildings. Vibration is a periodic motion of solid body about an equilibrium position. Vibration is caused by moving vehicles, operating motors, turbines and other stationary and mobile equipment. Short-term vibration causes minor, physiological changes that are not significant, such as slight increase of heartbeat, but it is a normal reaction to an unexpected stimulus. In struggling to suppress vibrations, muscles become more tense. In the context of human exposure, the main vibration frequency range is from 5 to 80 Hz. Hygienic norm HN 50: 2003 regulates measured vibration values, but the vibration modeling procedure does not set this rate. "

Railway transport, is one of the main producers of noise, and has a tremendous and negative impact on the environment. With the development of rolling stock, its speed also increases, this way producing more noise at the same time. When the train is moving on rails, moving parts and rails move the particles to the surrounding medium. The prevailing sound-induced wheel and rail contact frequency varies from 800 to 4,000 Hz "[5]. On the other hand, "Train noise depends on the train, the type of rail, the speed, mode, and so on. The noise of locomotives is 5-8 dBA higher than the noise caused by wagons. Electric trains cause a noise level of 8-10 dBA lower than a locomotive. Noise prevails at full load of the engine - when driving with acceleration, uphill, at high speed. Especially with high noise caused by railway traffic, there are encountered in residential areas close to the railway "[5].

Baltrenas and others (2008) states that "noise from railways occurs when trains run and sorting them at the stations" [1]. The equivalent noise levels created by trains running 7.5 m from the first axis of railway track at the speed of 40 km * h-1, are 84 dBA for passenger trains and 89 dBA for freight trains. Freight trains generate over 90 dBA noise. On the bases of emissions from rail transport, trains are divided into 10 categories according to their purpose (passenger, commercial) propulsion (diesel), brake construction (disk and pad) and others. (by-pass, fast, suburban) ".

It should also be noted that "noise from all trains increases with increasing speed and intensity. Increasing the train speed twice increases the noise level by about 10 dBA. This regularity applies to electric trains running at 60-80 km / h and for freight trains moving at 40 km / h "[2].

"French regard rail noise as the second most important issue after ensuring safe traffic of high-speed trains. For Japan, this has become a major problem when increasing train speeds. Speed increase also requires improval in train durability, driving comfort, and harmony between rail and its surroundings.

New trains use special shock absorbers to improve driving comfort, sound insulation material is used to improve sound insulation, special insulating bipolar transistors are used to reduce noise from the motor and other electrical equipment, new train shapes with smoother lateral surfaces are developed to reduce noise and minimize the pressure problems in tunnels and improve the train's aerodynamic characteristics."[3].

Based on sound emissions from rail transport, trains are divided into 10 categories according to their purpose (passenger, commercial) propulsion (diesel), brake construction (disk and pad) and others. (by-pass, fast, suburban) [2].

An analysis of various scientific sources and reports has shown that "the issue of rail noise is the greatest in Central Europe, where most of the population is affected by noise and rail vehicles (in particular Germany, Italy and Switzerland, and the high traffic volume in Poland, Austria, the Netherlands and France). In general, there are three main sources of rail noise: motor noise, rolling noise, aerodynamic noise "[8].

Baltrėnas and others emphasize that "the volume of noise caused by a railway vehicle depends on the type of rail, type and condition of the brakes, the type of braking system and the way of wagon coupling, axial load". Moreover, Bazar and Rutka argue that "the noise level also depends on the rotation of the wheels on the rails and short-circuited bands in rail joints" [3].

It should be emphasized that rail noise is mainly produced by freight trains and blocked trains made of older wagons, trains with old-fashioned engines, and this problem becomes acute at night. As a rule, higher rolling noise is due to poorly maintained rail vehicles and trains running under poorly maintained infrastructure. Aerodynamic noise is particularly relevant in high-speed lines. In many cases, they contain noise reduction equipment, such as noise barriers. They reduce the effect of rolling noise, but are usually too low to attenuate the pantograph noise. Engine noise is most heard at lower speeds, up to 30 km / h, rolling noise - at speeds over 30 km / h, and aerodynamic noise predominates at speeds above 200 km / h. The main noise source is rolling noise and it is typical for all types of trains.

Grubliauskas and D Butkus also state that "many railway lines were built long ago without any consideration of the impact of noise on the adjoining territory. On both sides of the railway there is a 100-meter wide sanitary protection strip, in which it was forbidden to build residential houses, schools, hospitals. In the Soviet times, town and district executive committees ignored this prohibition and allowed the construction of residential buildings the current residents of which suffer the noise and vibration of trains. Therefore, the efforts of the state, local administrations and the railways are necessary to address the noise problem [6].

3. Assessment of Noise Levels Caused by Passenger Wagons at Paneriai Railway Station

Taking into account that in the Soviet times municipal and district committees did not follow the requirements for a residential building near the railway, to this day there are quite a few such territories in Lithuania. This problem is especially acute in big cities. It is therefore important to assess the noise caused by rail transport and take all the necessary safety measures to mitigate the effect of noise.

Paneriai Railway Station was an intentional choice for this study, since not only the passenger train traffic here is among the heaviest in Lithuania (it is located between Vilnius and Kaunas regions), but also it is crossed by the main transit flows of freight wagons along the corridors B and D towards Klaipėda and Karaliaučius. The station sees an intense freight traffic between The East and West. Approximately 87 freight wagons and 96 passenger wagons pass the station every day.

In order to more accurately assess railway noise, the number of wagons passing through Paneriai station was calculated, and in this article, passenger trains were distinguished. Measurement begins when the train crosses the running line and ends when the last wagon passes the driving line. For measuring noise emitted by railway transport, two locations were selected near Paneriai Railway Station: 1) In the residential area near the house, where the distance to the railway track is 30 m. 2) Near the residential building, where the distance to the railroad is 100 m.

Before the measurements were conducted, it was assessed that the noise level allowed in the residential area (hereinafter LTL) should not exceed: 1) During the day (7 to 19 hours) - 70 dBA; 2) In the evening (19 - 22 hours) - 65 dBA, At night (22 - 7 hours) - 60 dBA [4].

The measurements taken on May 15th and 16th, 2018 in the evening were compared. Meteorological weather conditions for these days are given in the Table below.

To assess the noise levels, electric and diesel passenger trains were targeted (Figs. 1-4).

Table

Meteorological weather conditions < https://www.gismeteo.ru/diary/4230/>

Indicators	**15th day**	**16th day**
Temperature	+15,3 °C	~ +13 °C
Wind	South wind 2 m/s	Southwest wind 4 m/s
Air pressure	749,2 mm/Hg	745 mm/Hg
Humidity	80%	81%
Cloudiness	Partially cloudy	Cloudy
Precipitation	No rainfall	Rain

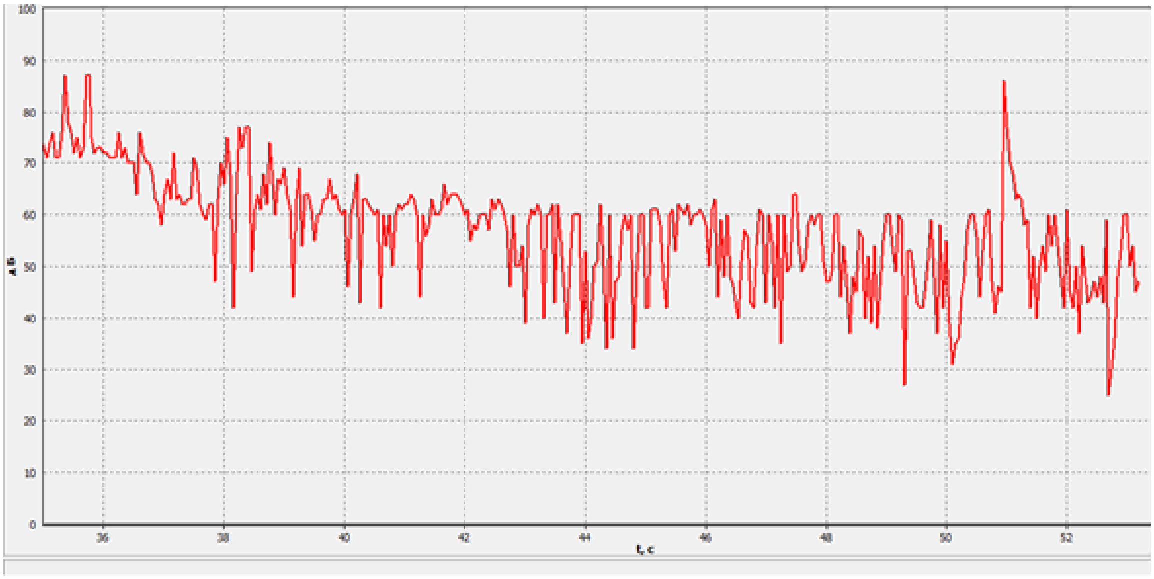


Fig. 1 2018-05-15 19:48 The noise level of passenger electric six wagon train (which has passed the station)

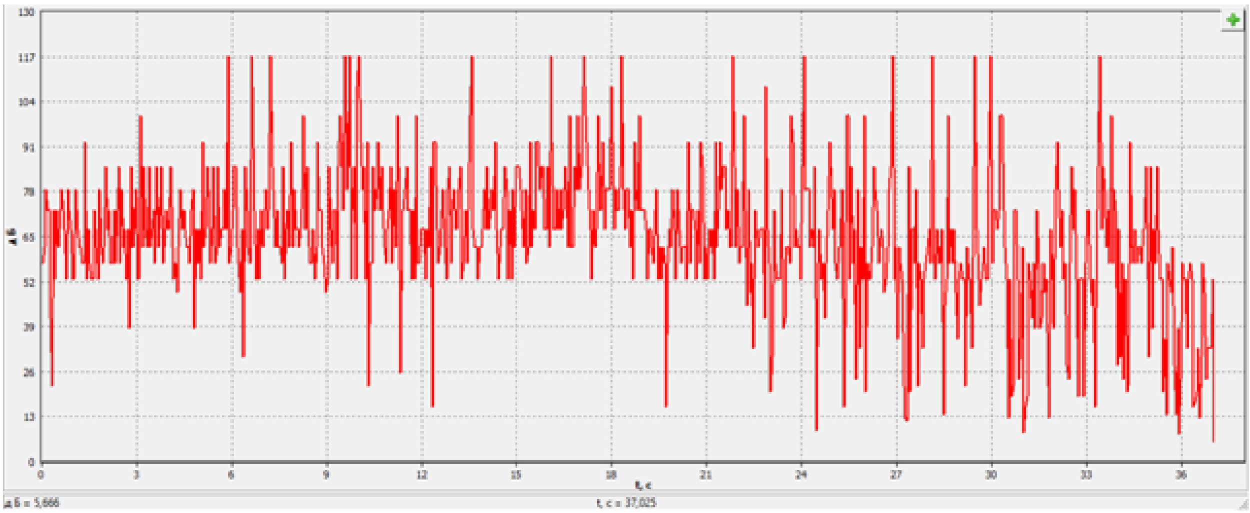


Fig. 2 2018-05-16 23:23 The noise level of passenger diesel three wagon train

Diagrams 1 and 2 present a comparison of the obtained results of noise level measurement outcomes of a three wagon electric passenger train and of a three wagon diesel passenger train. Apparently, depending on the weather conditions, type of train and the time and duration of the train, the diesel 3 wagon passenger train generates more noise. The maximum noise level reached by the electric train is 87 dBA, which exceeds 22 dBA in LTL, while the average noise generated during the train travel reaches 63.43 dBA, which means its noise level corresponds to LTL. The maximum noise level reached by a diesel train is 117 dBA, exceeding 57 dBA, while during driving, the average noise is 65,10 dBA, which means that its noise level is slightly above LTL. By comparing these results, it can be argued that diesel noise is significantly higher and is more harmful to the environment and human health and at night, people's rest is disturbed. It can be concluded that an effective way of reducing noise at night could be traffic of only electric passenger trains at night.

The survey also revealed that the level of noise depends not only on whether it is an electric or diesel train, but also how many wagons will form a train, whether it is at the station or not. In the evaluation of the diesel train noise, the number of wagons was also assessed (Figs. 3-4).

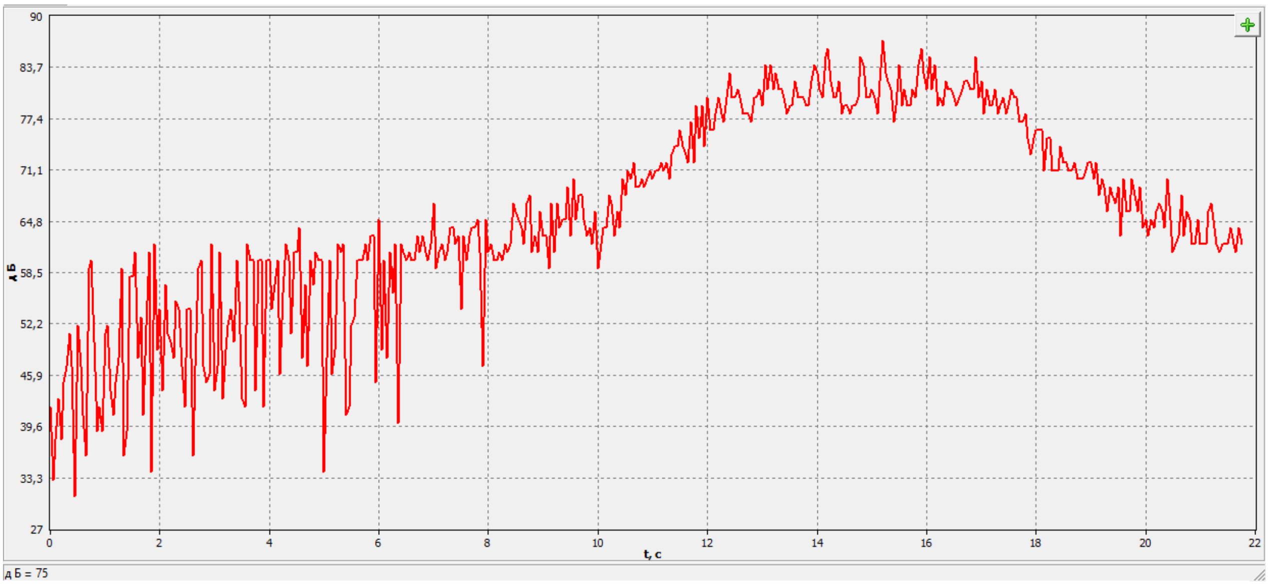


Fig. 3 2018-05-15 20:15 The noise level of passenger diesel six wagon train (which has passed the station)

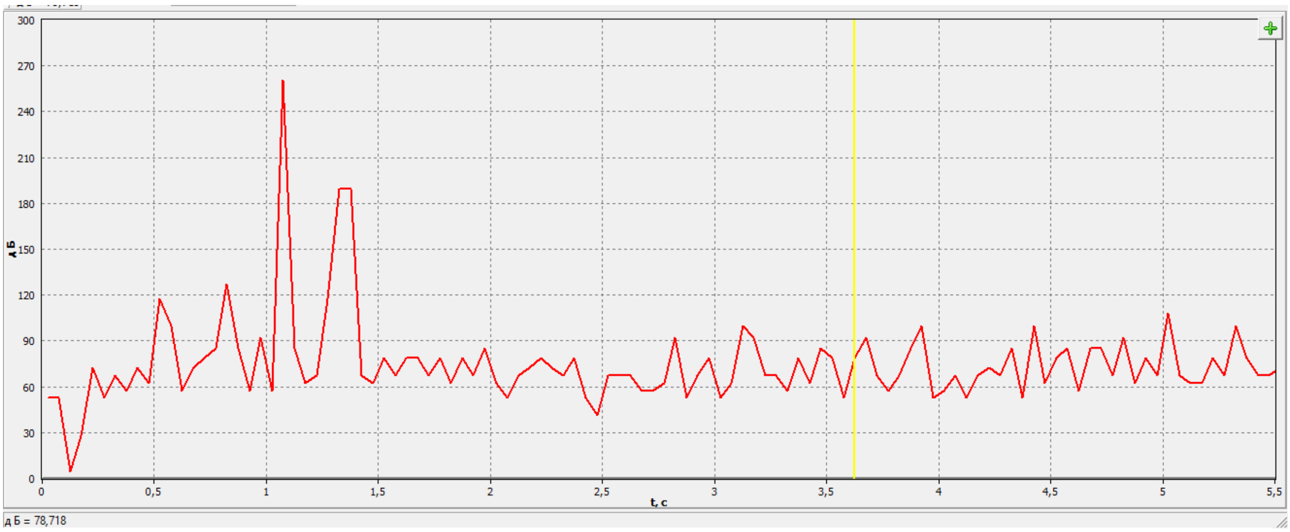


Fig. 4 2018-05-16 22:34 The noise level of passenger diesel two wagon train (which is standing at the station)

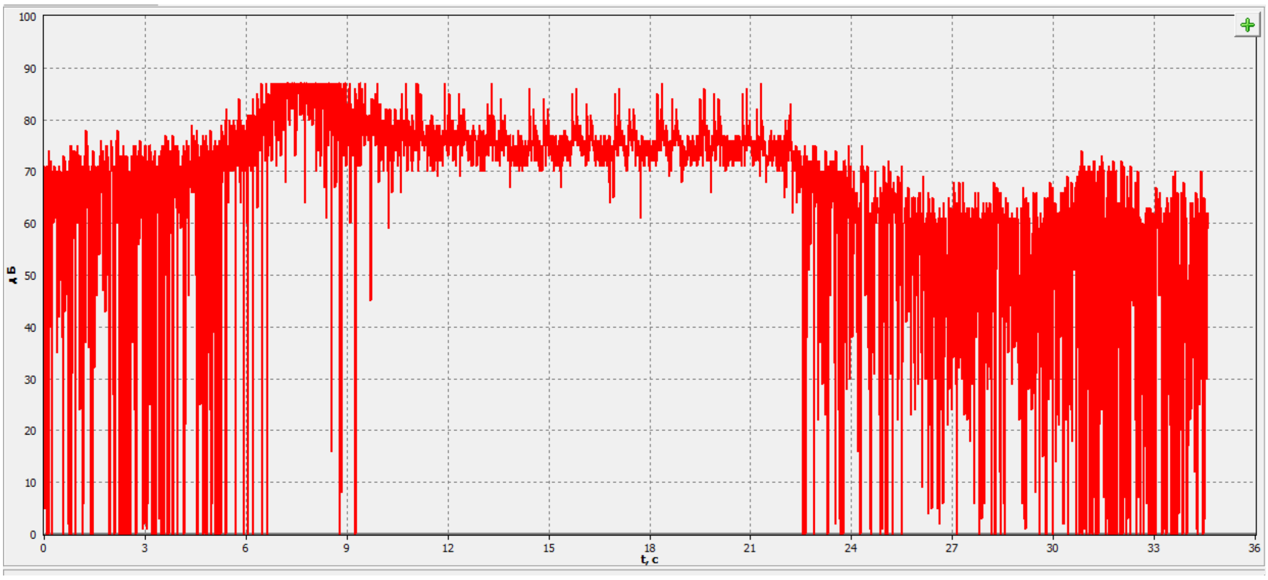


Fig. 5 2018-05-16 19:42 The noise level of passenger electric six wagon train

The diagrams compare the noise produced by two passenger diesel trains. Fig. 3 shows the results of the six wagon

train, the highest noise level at driving time was 87 dBA, higher than LTL 22 dBA, and average noise level 65.78 dBA, which means that the maximum is exceeded by LTL. The two wagon train which stops at the station shows that its noise level is higher than the 6 wagons passing through the station, the maximum reached noise level is 260 dBA, which means that the LTL is exceeded by 200 dBA and the average driving noise level is 87 dBA. These changes were probably due to altered meteorological conditions. The temperature during the measurement was + 13° C, relative humidity 80%. At the time of measurement, rain was transferred to the ice crystals, resulting in an average noise level of 2 wagon diesel trains reaching 75 dBA and a minimum above LTL.

During assessment of noise level of passenger electric six wagon train the following results were obtained. (Fig. 5).

Fig. 5 presents a diagram that shows the results of measurements of the noise level created by a six-wagon electric passenger train. It can be seen that the maximum noise level reached is 87 dBA and LTL exceeded - 22 dBA. Meanwhile, the average driving noise is 64.70 dBA, which does not exceed LTL but is close to the limit. It can be assumed that during the evening the station is passed by unbroken, shorter trains, regardless of type, which cause lower noise levels.

4. Conclusions

Railway noise is mainly generated by freight trains and train blocks made up of older wagons, as well as by trains with old-fashioned engines, and this problem is more prominent at night. Engine noise is most relevant at a lower speed, at around 30 km / h.

The main source of railway noise is rolling stock. It is typical for all types of trains. With the development of rolling stock, the speed of movement increases, and noise is increasing at the same time. When the train is running on rails, its moving parts and rails move the particles of the surrounding medium. The prevailing sound, driven by wheel and rail contact, varies from 800 to 4,000 Hz. Rolling noise is most prominent when the speed is over 30 km / h.

The survey measured the noise created by passenger trains at Paneriai railway station at two points and the results were compared with the permissible noise norm levels. The results showed that the highest noise is heard in Vilija g. up to 30 meters from the rails, and LTL exceeds the norms.

When analyzing noise created by passenger trains, electric passenger trains appeared to create smaller noise than diesel ones. The average noise caused by electric trains is 65.36 dBA and diesel is 70.65 dBA. In certain cases, the permissible noise levels are significantly exceeded. Therefore, it is necessary to continue the research in the future and to set the average values of LTL.

Application of noise prevention measures is essential at each railway station, especially if a residential area is nearby. It is possible to reduce noise by installing protective walls, using mixed brake pads for trains, fitting a wheel shock absorber, using rails with damping seals (rubber) and simply planting shrubs, various vegetation.

Reference

1. **Baltrėnas, P.; Butkus, D.; Oškinis, V.; Vasarevičius, S.; Zigmontienė, A**. 2008. Aplinkos apsauga. Technika, ISBN 978-9955-28-365-2
2. **Baltrėnas P.; Butkus D.; Nainys V.; Grubliauskas R.; Gudaitytė J**. 2007. Triukšmo slopinimo sienelės efektyvumo įvertinimas. Journal of environmental engineering and landscape management. Vilnius: Technika. ISSN 1648-6897 15(3): 125-134.
3. **Bazaras, Ž.; Rutka, A.** 2005. Geležinkelio riedmenų konstrukcijos. Laboratoriniai darbai. Kaunas: Technologija. 100 p.
4. **Cinkutė, N.; Judickij, R.; Bunga, A.; Valma, E.; Sladkevičienė, L.** 2018. Triukšmo lygio matavimų Panerių geležinkelio stotyje tyrimas, iš Transporto inžinerija ir vadyba: 21-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis", įvykusios Vilniuje 2018 m. gegužės 4 d., pranešimų medžiagos, Vilnius: Technika.
5. **Grubliauskas, R.** 2009. Aplinkos triukšmo ir jo mažinimo, taikant lengvas konstrukcijas, tyrimai bei skaitinis modeliavimas" Vilniaus: Technika ISBN 978-9955-28-431-4
6. **Grubliauskas, R.; Butkus, D.** 2007. Geležinkelio transporto keliamo triukšmo stotyse tyrimai, iš Aplinkos apsaugos inžinerija: 10-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis", įvykusios Vilniuje 2007 m. kovo 29 d., pranešimų medžiagos, Vilnius: Technika. 315–323. http://leidykla.vgtu.lt/conferences/Aplinka_2008/Aplinkos_konferencijos_PDF/5_sek_40_Grubliauskas_Gelezinkelio.pdf"
7. **Keblytė, M.; Dėdelė, A.** Geležinkelio transporto keliamo triukšmo taršos vertinimas Kaune [interaktyvus]. Vilnius: [žiūrėta 2018 m. vasario 26 d.] Prieiga internetą < http://sauga.asu.lt/wp-content/uploads/sites/8/2015/03/102-104_Keblyte_Dedele_II_56.pdf
8. Geležinkelio akustinės taršos mažinimas. 2012. [interaktyvus]. Vilnius: Europos Sąjungos vidaus politikos generalinis direktoratas. Europos Parlamento Transporto ir turizmo komitetas [žiūrėta 2018m. gegužės 17d.].< http://www.europarl.europa.eu/RegData/etudes/etudes/join/2012/474533/IPOL-TRAN_ET(2012)474533(SUM01)_LT.pdf

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

IoT solutions for Internal Combustion Engine Test Bench

A. Prokhorenko[1], D. Samoilenko[2], S. Kravchenko[1], I. Karyagin[1]

[1]*National Technical University "Kharkiv Polytechnic Institute", Kyrpychova 2, 61002, Kharkiv, Ukraine*
[2]*Warsaw University of Technology, Narbutta 84, 02-524 Warsaw, Poland, E-mail: samoilenko@simr.pw.edu.pl*

Abstract

In recent years, the concept of Internet of Things extends not only for devices used privately, but also to industrial facilities. Thus, the development of a distributed network infrastructure in the Industrial Control System led to the emergence of Industrial Internet of Things (IIoT), which allows for a significantly improve the possibilities of saving time and means of production for industrial enterprises due to the connection of all their processes at the executive level. Based on developed by authors concept, a schematic diagram of the "smart" test bench system used for the research of diesel engine is created and implemented. An original scheme for routing data in Internet has been developed. It gives the possibility to connect different customers for sending and receiving data using various protocols. As a data aggregator, the ThingSpeak ™ cloud service is selected, and the integrated MATLAB® mathematical package is used as the analyzer.

KEY WORDS: *Internet of Things, Test Bench, Diesel Engine*

1. Introduction

Internet of Things (IoT) is a set of physical devices, vehicles and other technical objects equipped with electronics, software, sensors, drives and network connection, that allow these objects to collect and exchange data independently. Moreover, each such object is identified uniquely through the built-in computing system and has ability to interact with other objects within the existing infrastructure of the worldwide *Internet* network [1,2]. According to experts, by the year 2020, the *Internet of Things* will include of about 50 billion devices [3].

Starting from 2017, the concept of *Internet of Things* extends not only for devices used privately, but also to industrial facilities. Thus, the development of a distributed network infrastructure in the *Industrial Control System* led to the emergence of *Industrial Internet of Things* (IIoT), which allows for a significantly improve the possibilities of saving time and means of production for industrial enterprises due to the connection of all their processes at the executive level.

Such technological processes include, among other things research and exploitation of internal combustion engines. Undoubtedly, the introduction of full or partial automation in the life cycle of these products will significantly improve their technical level, the quality and production speed as well as the comfort of exploitation.

It should also be noted that "communication" of things is done through "cloud" information technology using a special communication protocol MQTT (*Message Queue Telemetry Transport*), which is the standard for IoT because of its simplified service information, availability of publication / subscription model and bidirectional opportunities.

Based upon foregoing statements - **the relevance of the task**, defined in the present scientific study, is indisputable.

The purpose of the work is the implementation of *Industrial Internet of Things* in the life cycle of an internal combustion engine through creation of an "smart" research test bench.

2. The Concept of the Telemetry System and its Implementation

The main idea of present research is to create a telemetry system used by remote users and capable for real-time visualization and analysis of engine's parameters obtained on the test bench. Thus the results of such an analysis can be used both for the adoption of subsequent scientific and engineering solutions and for the operational management of the test facility as well. Schematically, the concept is illustrated in Fig. 1 where there is one of the crucial elements is shown which is *IoT Broker - the Internet* source that allows to collect, store and provide on request all the telemetry data.

The realization of the proposed idea is based on the schematic diagram of data routing developed by the authors. Routing data schematic diagram takes into account the protocols of data transmission and shown in Fig. 2.

It should be noted that this scheme is based on the electronic fuel management system of the diesel engine, the composition and algorithm of which is open and described in detail in [3]. The electronic control unit of the engine has a microcontroller ATmega328, the parameters of which are presented in Table 1. The microcontroller ATmega2560 is selected as the basis for the electronic control unit of the "smart" test bench because it has acceptable parameters (see Table 1). The interaction of these controllers is realized by means of consecutive consistent transmission of data through their serial ports.

The data transmitted between the controllers are the parameters of the automatic fuel management system in the form of *X*, *Hp*, *n* - the current position of the engine control unit, the rack position of high pressure fuel delivery pump and the crankshaft rotation speed respectively. The rest of the operating parameters of the engine are received in the form

of signals from analog sensors directly to the input ports of the electronic control unit of the test stand. These are the magnitudes: *Mc* - loads on the engine; *Gfuel, Gair* - fuel and air consumption; *Pair, Tair* - pressure and air temperature at the inlet; *Twater, Toil, Teg* - temperatures of a cooling liquid, oil and exhaust gases temperature. In our opinion, such a set of parameters is sufficient for creation a predicative statistical model of engine operation.

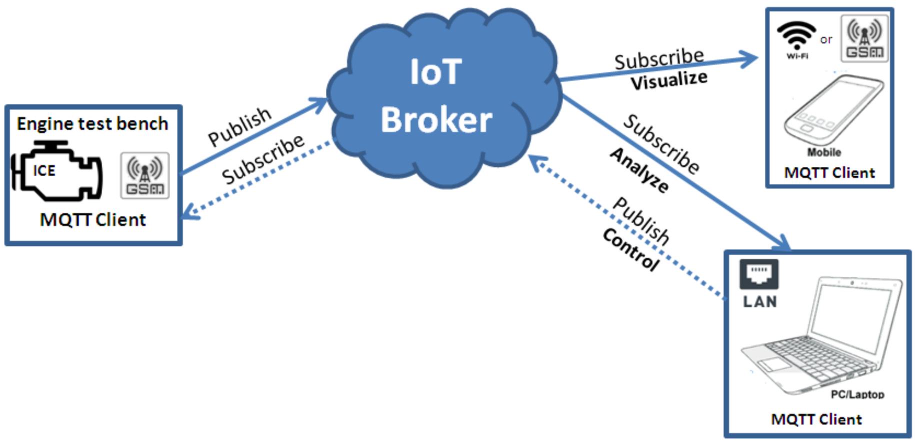


Fig. 1 The Concept of Smart Test Bench

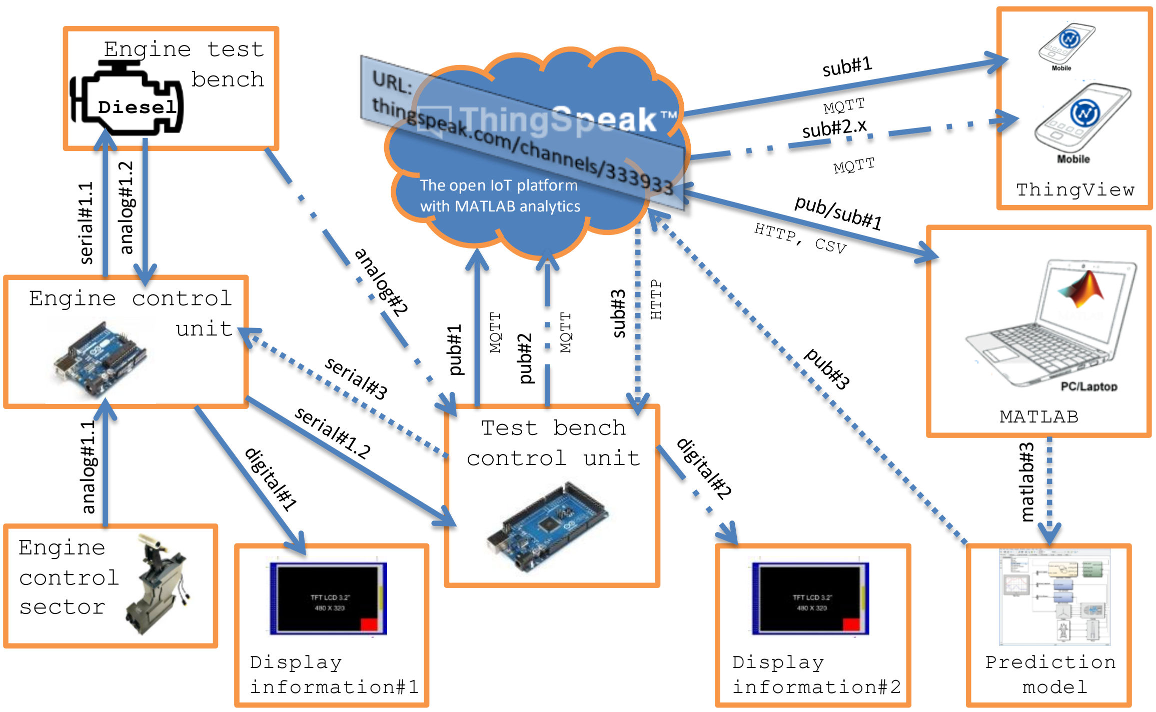


Fig. 2 Data routing through the Cloud

Table 1

Technical characteristics of microcontrollers

Microcontroller	ATmega328	ATmega2560
Clock frequency	16 MHz	
Flash memory	32 KB	256 KB
Boot Flash memory	0,5 KB	8 KB
RAM	2 KB	8 KB
EEPROM	1 KB	4 KB
Digital Inputs / Outputs	14	54
Analog inputs	6	16
DC current through the inputs / outputs	40 mA	
Input voltage of the ports	7-12 V	
Operating Supply Voltage	5 V	

The research engine is a single-cylinder diesel engine with a power output of up to 50 kW at a crankshaft rotation speed of up to 2500 rpm. Dimensions of the cylinder: bore 120 mm, stroke 140 mm. The installation is characterized by the following design features.

Injection of fuel into the cylinder is carried out by a high-pressure fuel supply with an individual fuel pump (*Unit Pump System*, UPS).

- Lubrication system - autonomous, with a dry crankcase.
- Cooling system - liquid, autonomous, with separate flows of coolant to the engine block and cylinder head.
- The engine is started by means of an electric load device included in the test setup.
- Lanchester type balancing mechanism.
- There is a gas channel in the cylinder head for installation pressure indicator.

The test bench is equipped with all the necessary instruments and sensors for measuring the parameters of the engine.

The Internet-client of the electronic control unit of the test bench is the GSM-900 mobile communication module, operating according to the 2G / GPRS standard. The module suits perfectly for a mobile telemetry system, and its transmitting power is sufficient to support packet data transfer using the MQTT protocol with a short time interval.

As a cloud aggregator and data storage medium, the ThingSpeak ™ server is used as a remote resource. MATLAB® mathematical package integrated into the resource is utilized as data analyzer [4]. The choice of this particular resource is explained by the convenience of using all benefits from the environment of scientific and engineering mathematical calculations offered by MATLAB® software for data analysis, mathematical models creation and virtualization of research [5]. On the ThingSpeak ™ server, this project has its own channel, which is publicly accessible through the URL address *https://thingspeak.com/channels/333933*.

For connecting and managing data on the ThingSpeak ™ server, MATLAB® package includes special ThingSpeak Fetch and ThingSpeak Support Toolbox libraries [6]. The results of processing incoming data can be opened to the public access on the server or used for local needs, for example, to create a virtual predictive model. An example of local processing and visualization of data using MATLAB® package is shown in Fig. 3.

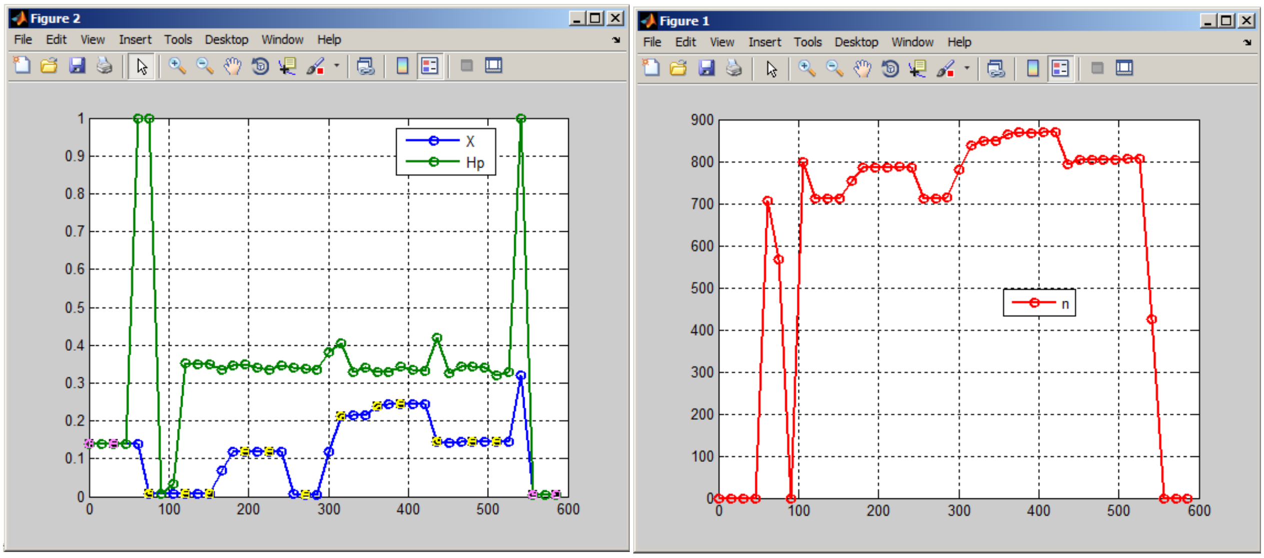


Fig. 3 An example of data processing and visualization in MATLAB

Android-based ThingView application could be used in the mobile Internet-devises for monitoring data incoming to ThingSpeak ™ server.

The prospective tasks to be solved within the framework of this project are:

- reduction of the sampling interval for data packets transmission up to 1 s;
- creation of a predictive mathematical model of the experimental setup;
- creation of a feedback data stream for the organization of remote automatic (or manual) diesel control.

3. Conclusions

Based on developed in present study concept, a schematic diagram of the "smart" test bench system used for the research of diesel engine is created and implemented.

As a data aggregator, the ThingSpeak ™ cloud service is selected, and the integrated MATLAB® mathematical package is used as the analyzer.

Practical testing of the developed system showed its reliability, ease implementation and confirmed the correctness of the developed concept.

An original scheme for routing data in *Internet* has been developed. It gives the possibility to connect different customers for sending and receiving data using various protocols.

References:

1. **Brown, E.** Who Needs the Internet of Things? The Linux Foundation [online cit.: 2016-09-13]. Available from: www.linux.com/news/who-needs-internet-things
2. **Nordrum, A.** Popular Internet of Things Forecast of 50 Billion Devices by 2020 Is Outdated. IEEE [online cit.: 2016-08-18]. Available from: www.spectrum.ieee.org/tech-talk/telecom/internet/popular-internet-of-things-forecast-of-50-billion-devices-by-2020-is-outdated
3. **Прохоренко, А.О.; Кравченко, С.С.; Карягін, І.М.; Вовк, Є.Г.; Думенко, П.І.** 2017. Розробка універсального електронного регулятора частоти обертання колінчастого валу дизеля. Двигатели внутреннего сгорания, Харьков, 2: 35-39.
4. Learn More About ThingSpeak. The MathWorks, Inc. [online cit.: 2017-03-22]. Available from: www.thingspeak.com/pages/learn_more
5. Developing an IoT Analytics System with MATLAB, Machine Learning, and ThingSpeak. The MathWorks, Inc. [online cit.: 2016-03-22]. Available from: www.mathworks.com/company/newsletters/articles/developing-an-iot-analytics-system-with-matlab-machine-learning-and-thingspeak.html.
6. ThingSpeak Support from Desktop MATLAB. The MathWorks, Inc. [online cit.: 2017-03-22]. Available from: www.mathworks.com/hardware-support/thingspeak.html

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Influence of the Vehicle Weight on the Selected Vehicle Braking Characteristics

J. Ondruš[1], J. Vrábel[2], E. Kolla[3]

[1]*University of Zilina, Univerzitná 8215/1, 010 26 Zilina, Slovak Republic, E-mail: jan.ondrus@fpedas.uniza.sk*
[2]*University of Zilina, Univerzitná 8215/1, 010 26 Zilina, Slovak Republic, E-mail: jan.vravbel@fpedas.uniza.sk*
[3]*Institute of Forensic Research and Education of University of Zilina, Ulica 1. mája 32, 010 01 Zilina, Slovak Republic, E-mail: eduard.kolla@uzvv.uniza.sk*

Abstract

For the accident process analysis the correct information is very important, as the crucial factor of the accident process analysis is the full braking deceleration of the vehicle. The aim of the article was to perform a practical measurement of the braking characteristics of a selected medium commercial vehicle (MCV), evaluate and compare the measured data that will be used in the forensic expert practice. 18 measurements on a different surfaces were performed in total, out of which 12 were performed with an unloaded vehicle and 6 with loaded vehicle. The individual data were collected during the dynamic driving trails with the measuring device XL MeterTM Pro. For the data processing the SW XL VisionTM, which is a part of the measuring equipment and the SW PC-Crash, was used. The conclusion contains an analysis and comparison of the measured data and an evaluation of the measurement.
KEY WORDS: *medium commercial vehicle (MCV), intensive braking, decelograph XL Meter^{TM} Pro, PC-Crash, loaded, unloaded vehicle*

1. Introduction

The braking process can be defined as an intended lowering of the vehicle’s speed. Intensive vehicle braking is usually an essential defensive reaction of the driver in order to avoid an accident. The braking itself, or stopping of the vehicle, is processed using the braking system. A high quality and reliable braking system, or braking set up, is the most important part when considering the active vehicle safety. Another important factor is the drivers᾿ proper control of the brakes - correct driving technique [2, 9].

Braking distance is one of the most important characteristics of the vehicle’s braking system. Its length depends on various factors connected to the technical part of the vehicle, driving surface or the driver. When analysing an accident and specifying its cause, the braking distance and the full braking deceleration of the vehicle can be one of the most important data input [6].

The main purpose of the vehicle’s safety system is to protect health and lives of the passengers. The general purpose is to minimize the probability of an accident and in case of an accident to protect the passengers and in a certain way to protect the other participants, such as pedestrians, bikers or other vehicles [7].

2. Description of the Experimental Vehicle

A medium commercial vehicle (MCV) of the category N3 make MERCEDES ATEGO 1823 (Daimler Chrysler), production year 05/2000, displacement 6 347 cm^3, max power 170 kw at 1 800 rpm, max torque 810 Nm at 1 600 rpm (Fig. 1) was used for the measurement.

Fig. 1 The experimental vehicle MERCEDES ATEGO 1823

This vehicle equipped with the compression ignition engine has a manual synchronized 6-grades change gear unit. The vehicle superstructure is lifting and equipped with a hydraulic arm of the make Palfinger. The respective

vehicle has the operative weight 10 130 kg, highest permitted total weight is 18 000 kg.

Tyres on front axle were of the dimensions Agate ST011 315/80 R 22,5 156/152 L, Tubeless. Tyres on rear axle (doubled) were of the dimension Continental HDR2 315/80 R 22,5 156/152 L, Tubeless, marked as regrovable. The profile depth on front axle was 19,0 mm, on rear axle was 9,0 mm. The tyres were pumped as given by the producers (7,5 bar). The medium commercial vehicle and its braking system was in the technical conditions with no defects.

The measured vehicle is equipped with a twocircuit airbraking system. Besides, it has the functional, parking, additional and emergency brake. The active element installed is the antiblocking system ABS and ALB system. The ALB system divides the braking power on the individual vehicle axles depending on the load, but it cannot stop blocking the wheel during braking. When the vehicle is unloaded, the ALB system decreases the braking pressure on the regulated rear axle.

3. Decelograph XL Meter^{TM} Pro

Measurement device XL Meter^{TM} Pro of the 3rd generation was used for measuring (Fig. 2). It is a universal accelero/decelerometer with the alphanumercid LCD display. It serves to measure and evaluate vehicle acceleration and the state of its service brakes; it´s easy to operate as it uses only 3 buttons placed at the top of the device box, each of them being of a different colour (black, green, red) and therefore of a different function [12].

Fig. 2 XL Meter^{TM} Pro [12]

The device is powered by a battery but it can also be connected via an external source. From the technical point of view, it consists of three main parts: electronics, a vacuum suction cupule and an articulated arm which allows customizable mounting. XL Meter^{TM} Pro is easy to attach to the desired location on the surface of the vehicle windshield or any other smooth surface and it can be fixed to the surface by turning the lever of the vacuum suction cupule. The device is built-in into an aluminium box which is purpose-designed to provide easy controllability and installation. The articulated arm allows zero point calibration while being installed on the vehicle windshield by means of the vacuum suction cupule [8, 11].

There are two slots at the back panel; nine-pin D-SUB connector RS-232 allows connection with the computer and it may also be used to connect the brake pedal sensor as well as output signal control and the round slot is used to power the device from the external source (CC-in adapter) [3]. The 14-bit measuring technology has been improved in the process of new XL Meter^{TM} Pro development. Thanks to its increased storage capacity it is now possible to realise 8 measurements without the necessity to transfer data directly into a computer. The new functions of synchronisation and remote control enable easier and more comfortable usage. The modular architecture makes XL Meter™ Pro the ultimate device either for speed-up or brake performance tests. The electronic system of the device continuously records values of output signal voltage during the measurement, with the sampling rate of 200 Hz, i.e. the values are measured and recorded every 5 ms. There is an automatic off position recognition built-in in the device, so the precise zero point setting is not that necessary. The device records the course of acceleration within a span of 40 seconds from the moment of being turned on [4, 10].

4. Measuring Methodology

The aim of the measurement was to determine the influence of the vehicle weight on the selected vehicle braking characteristics on a different surfaces. The monitored basic parameters of braking were the velocity at the beginning of fully braking deceleration, braking distance, braking time and full braking deceleration.

18 measurements on different surfaces (dry – Fig. 3, a, wet – Fig. 3, b, gritted surface – Fig. 3, c) were performed in total, out of which 12 were performed with an unloaded vehicle and 6 with loaded vehicle, at the speeds 30 km/h and 50 km/h. During the testing the experimental vehicle was loaded with 2 persons (driver + co-pilot, who operated the measuring device). The respective vehicle has the operative weight of 10 130 kg, in case of loaded vehicle by 5 000 kg more (loaded with a gravel-like material).

The experiment was carried out on 21. 11. 2016 on the unpublic road in the village Švedlár, in the district of Gelnica, region of Košice. The surface conditions were: dry asphalt runway with the estimated adhesion factor of range 0,8 – 0,90 and the runway temperature was of 5°C. The temperature of ambient air was 9°C with very low speed wind, therefore its impact on the measurement can be ignored. Prior to the experiment we carried out calibration and test

measurements to determine the necessary measurement characteristics (location of the braking manoeuvre, installation and calibration of the system, etc.). The length of the experimental track was approximately of 150 m. Certain measurement inaccuracy was caused by the surface gratient estimated at 3%.

a b c

Fig. 3 Surface detail

Measurement device XL Meter™ Pro was installed on the inside MERCEDES ATEGO 1823 windshield by means of the vacuum suction cupule.

The decelerograph was fixed by means of the vacuum suction cupule on the inside windshield during the measurement. The device was positioned in a way so that its measuring axis was parallel to the drive direction and so its controls were within reach of operation. The device switches into calibration mode after being switched on and successful completion of the automatic system control. The mode then displays current value of measured acceleration. If a vehicle stands still on the horizontal surface, the displayed value is to be of 0 $m.s^{-2}$. Any deviation can be rectified by manipulating the devices´ butt hinge so its measuring axis is in the closest possible horizontal position [5].

The target process to be observed was braking on the point of the swerving, with the fully applied service brake. The driver set the vehicle in motion to the desired speed of 30, and then 50 $km.h^{-1}$. Then at the moment of the desired steady speed the driver violently pushed the service brake pedal. Braking was being conducted until the vehicle reached the zero speed.

It was necessary to stop data recording when the vehicle reached the zero speed, by pushing the off button. All these data were being recorded and were available in a complete file at the end of the experiment. The experiment measurement was repeated after a short break.

After the last measurement was completed we measured the brakes temperature with the thermometer. The temperatures are processed in the following Table 1.

Table 1

Brakes temperatures on individual axles

Axle	Brakes temperature [°C]
1	98,5
2	52,3

5. Processing of Measured Data

For processing of results acquired from the measuring device XL Meter™ PRO the programe XL Vision™ and PC Crash 10.9 were used (Fig. 4). For the necessary tables and graphs MS Excel was used. All data measured by XL Meter™ Pro can be saved and evaluated later offline. Individual data are stored in the permanent memory so they are accessible even after the device is off but only until being rewritten [1].

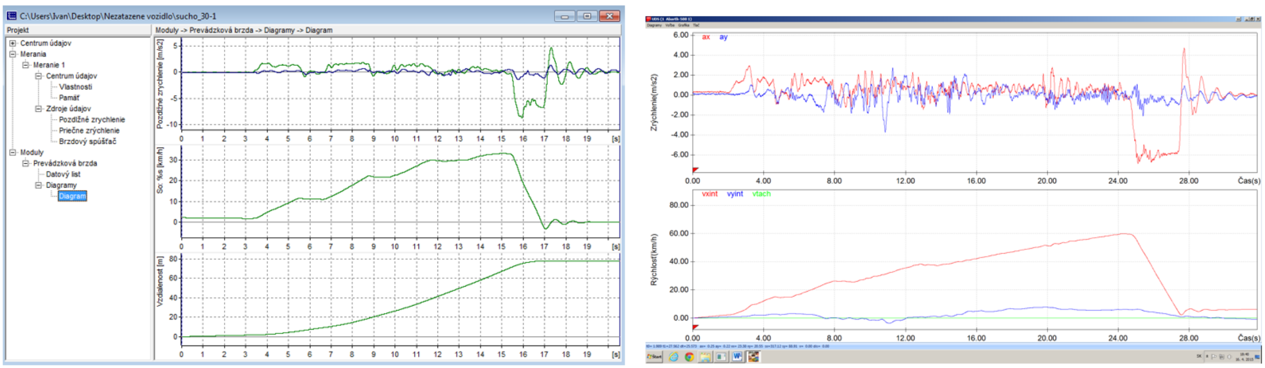


Fig. 4 The view of SW XL Vision™ and PC Crash 10.9 [13]

Communication and transfer of the measured data between a PC and the XL Meter™ Pro device and its sequential processing is provided by the freeware XL Vision™. In the XL Vision™ programme it is possible to display and save the measured data as the measurement process diagrams. These files with the measured data had to be saved in the programme XL Vision™ as a file PC Crash (*.asc), so that they can be opened in the programme PC Crash 10.9, where the data can be precisely processed and evaluated [1].

The graphic evaluation of the respective experiment provides us with three graphs (XL Vision™). The first one shows the addiction of middle braking deceleration on time. The second graph shows the addiction of speed on time. The last one shows the addiction of distance on time.

6. Measured Data Evaluation

6.1. The Results and Comparison of the Unloaded Vehicle

The following chart 2 shows the velocities at the beginning of fully braking deceleration, calculated mean values for fully braking deceleration, time and distance data that the vehicle has passed over this section of the various velocity of vehicle on a different surfaces - unloaded vehicle With an unloaded vehicle we carried out two measurements for each type of surface and for both velocities.

Table 2

Evaluation of the measured data - unloaded vehicle

		Velocity at the beginning of fully braking deceleration [km/h]	**Braking distance [m]**	**Braking time [s]**	**Mean fully braking deceleration [m/s^2]**	**Average mean fully braking deceleration [m/s^2]**
30 km/h	**Dry surface**	31,75	5,72	1,36	6,82	6,75
		31,98	5,91	1,35	6,68	
	Wet surface	32,77	10,10	2,17	4,34	4,28
		31,90	9,33	2,02	4,21	
	Gritted surface	31,67	6,14	1,37	6,30	6,08
		30,83	6,27	1,61	5,85	
50 km/h	**Dry surface**	46,52	13,23	2,01	6,31	6,23
		45,59	13,64	2,21	6,15	
	Wet surface	48,81	16,85	2,53	5,27	5,13
		53,41	22,08	2.998	4,98	
	Gritted surface	49,43	15,87	2,29	5,94	6,06
		50,51	15,91	2,21	6,18	

The highest average full braking deceleration was in both cases reached on the dry surface, 6,75 m.s^{-2} by 30 km/h, and 6,23 m.s^{-2} by 50 km/h, followed by the gritted surface and the wet surface, where the values reached, 4,28 m.s^{-2} by 30 km/h, and 5,13 m.s^{-2} by 50 km/h (Fig. 5).

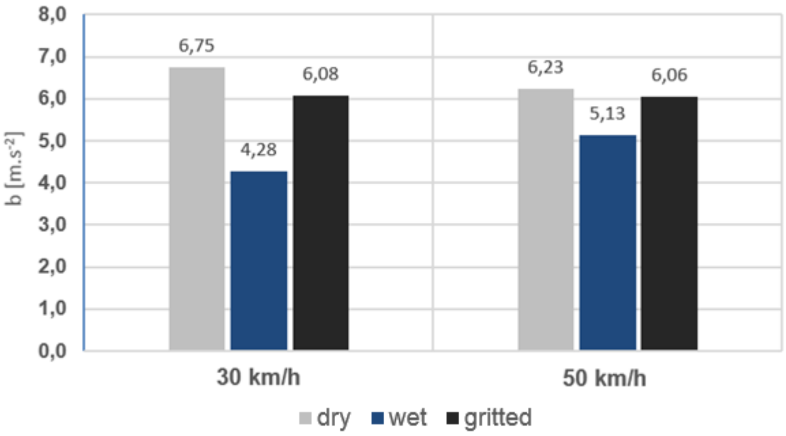


Fig. 5 Mean fully braking deceleration comparison - unloaded vehicle

To compare the individual data, we calculated the average values of the measured data shown in the Table 2 and then we created a graphic comparison for both velocities (Figs. 6 and 7).

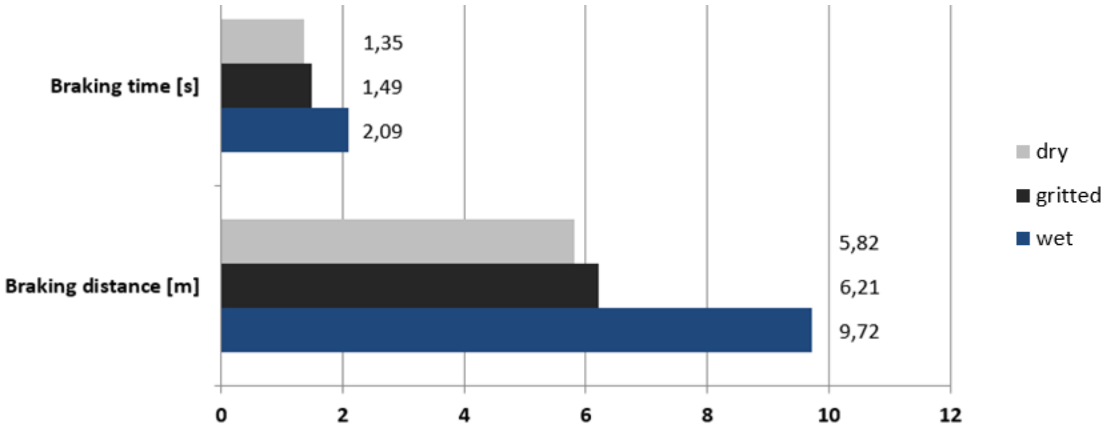


Fig. 6 Graphic comparison of data at the velocity of 30 km/h on different surfaces - unloaded vehicle

Fig. 6 shows that the differences between the dry surface and the gritted surface are not so significant as in case of the wet surface. Braking distance on the wet surface, compared to dry surface, was longer by 3,9 m, which represents 67,0% grow, braking distance on gritted surface was longer by 0,39 m, which represents a grow of 6,7%. Braking time on wet surface was longer by 0,74 s, on gritted surface by 0,15 s.

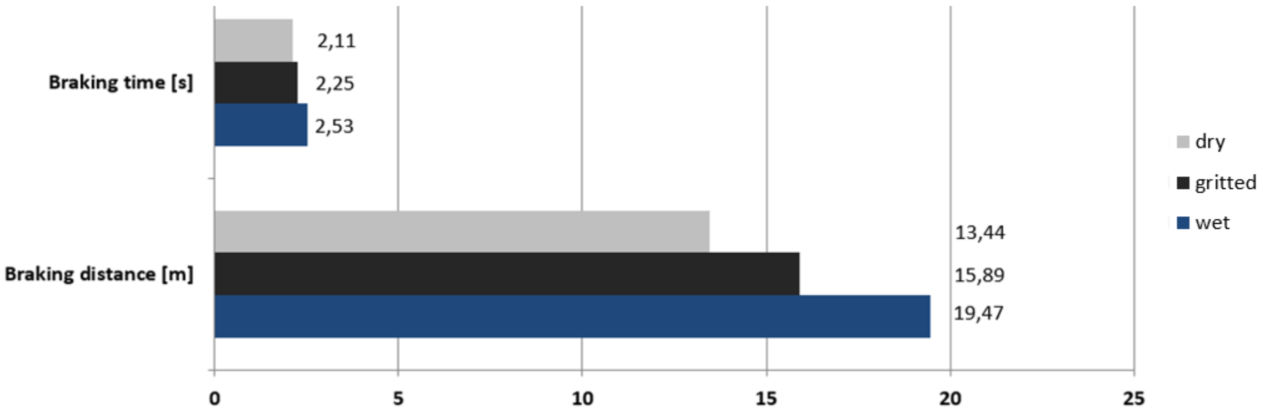


Fig. 7 Graphic comparison of data at the velocity of 50 km/h on different surfaces - unloaded vehicle

Fig. 7 shows that in this case the difference among the dry, wet and gritted surfaces is more significant. Braking distance on wet surface grew by 6,0 m, which represents a 44,8 % grow, braking distance on gritted surface grew by 2,45 m, which is a 18,2% grow. Braking time on wet surface grew by 0,42 s, on gritted surface by 0,14 s.

6.2. The Results and Comparison of the Loaded Vehicle

The following chart 3 shows the velocities at the beginning of fully braking deceleration, calculated mean values for fully braking deceleration, time and distance data that the vehicle has passed over this section of the various velocity of vehicle on a different surfaces - loaded vehicle. For this case we performed only one measurement for each surface type and for both velocities.

Table 3

Evaluation of the measured data - loaded vehicle

		Velocity at the beginning of fully braking deceleration [km/h]	Braking distance [m]	Braking time [s]	Mean fully braking deceleration [m/s^2]
30 km/h	Dry surface	33,54	6,78	1,45	6,40
	Wet surface	32,78	7,48	1,63	5,54
	Gritted surface	30,64	6,05	1,33	5,96
50 km/h	Dry surface	47,69	14,15	2,17	6,24
	Wet surface	53,35	20,91	2,46	5,25
	Gritted surface	52,29	17,37	2,42	6,07

The highest average full braking deceleration was in both cases reached on the dry surface, 6,40 m.s^{-2} by 30 km/h, and 6,24 m.s^{-2} by 50 km/h. This was followed by the gritted surface and the wet surface, 5,54 m.s^{-2} by 30 km/h, and 5,25 m.s^{-2} by 50 km/h (Fig. 8).

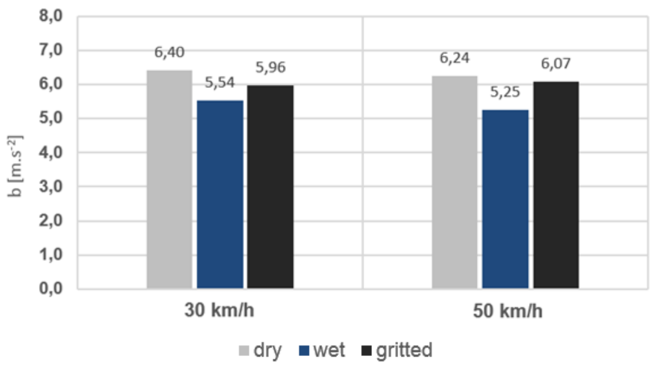


Fig. 8 Mean fully braking deceleration comparison - loaded vehicle

To compare the individual data, we calculated the average values of the measured data shown in the Table 3 and then we created a graphic comparison for both velocities (Figs. 9 and 10).

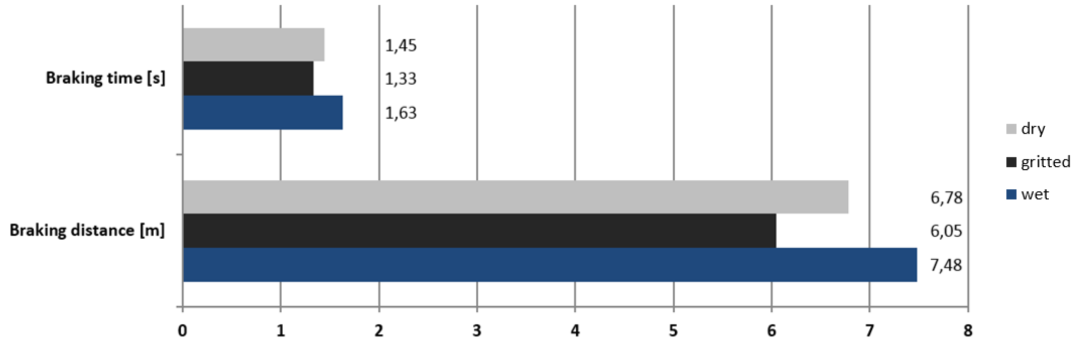


Fig. 9 Graphic data comparison for the 30 km/h velocity on different surfaces - loaded vehicle

Fig. 9 shows a curiosity, data measured on the gritted surface are more effective than the ones on the dry surface. This effect was caused by the lower velocity at the beginning of fully braking deceleration (by nearly 3 km/h), compared to the dry surface. Braking distance on the wet surface, compared to dry surface, grew by 0,7 m, which shows a growth of 10,3%.

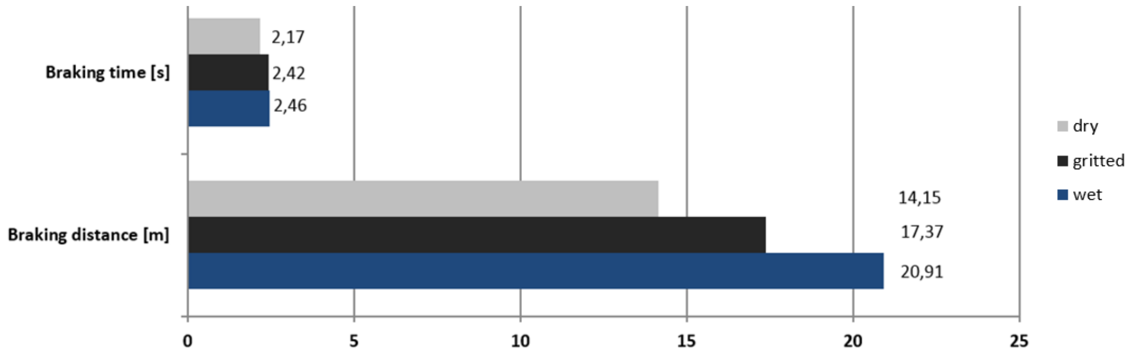


Fig. 10 Graphic data comparison for the 50 km/h velocity on different surfaces - loaded vehicle

Fig. 10 shows that in this case the difference among the individual surfaces is more significant. Braking distance on the wet surface, compared to dry surface, grew by 6,8 m, which represents a 47,7% grow, braking distance on the gritted surface grew by 3,22 m, which is a 22,7% grow. Braking time on the wet surface grew by 0,29 s, on gritted surface by 0,25 s.

Table 4 shows the average values of mean fully braking deceleration on the individual surfaces with both loaded and unloaded vehicle. Considering that the velocity does not influence the braking deceleration, also the values for both velocities were averaged.

Table 4

Average values of mean fully braking deceleration

	Dry surface	**Wet surface**	**Gritted surface**
Unloaded vehicle	6,49 m/s^2	4,73 m/s^2	6,07 m/s^2
Loaded vehicle	6,32 m/s^2	5,40 m/s^2	6,02 m/s^2

7. Conclusion

Our experiment consisted of 12 deceleration measurements on dry, wet a gritted road surface with the sampling rate of 200 data per second. Decelograpf Inventure XL Meter™ Pro is a Professional device for analysis of acceleration and deceleration of different vehicles such as motorcycles, passenger cars, busses, commercial vehicles, agricultural machines, trucks and etc.

An important contribution of this experiment was the practical measurement of the braking behaviour of the medium commercial vehicle (MCV), in particular focus on the braking distances and average full braking deceleration. This value is very important for the Road Traffic Experts when elaborating the Forensic Expert's Reports of traffic accidents, where it represents the core entry value of braking behaviour of the respective vehicle; or alternatively in other areas, where the measured results can help to achieve the solution.

During all measurements we aimed to reach the precise demanded velocity, which in more cases we did not succeed. This was caused by a not precise speed indicator installed in the vehicle and the measuring device. Therefore we need to consider the differences in the initial velocities for individual measurements, which directly influenced braking distance and braking time. In some cases the differences were as much as 5 km/h. We also need to take into account the driver’s factor and pressure on the braking pedal, which might have not been identical for all measurements. This could also have influenced the measured parameters.

For further clarification of the influence of the vehicle weight on the selected vehicle braking characteristics, more driving tests and measurements would have to be performed, mainly with higher initial vehicles velocities. We would most probably also detect more significant differences in the braking distances and the reached braking deceleration.

Acknowledgements

This contribution/publication is the result of the project implementation:
2/KCMD/2018
VEGA no. 1/0436/18 - Externalities in road transport, an origin, causes and economic impacts of transport measures.
Centre of excellence for systems and services of intelligent transport II, ITMS 26220120050 supported by the Research & Development Operational Programme funded by the ERDF.

References

1. **Burg, H.; Moser, A.** 2009. Handbuch Verkehrsunfall-rekonstruktion. Vieweg+Taubner. Wiesbaden.
2. **Barta, D.; Mruzek, M.; Labudal, R.; et al.** 2018. Possibility of increasing vehicle energy balance using coasting. In: Advances in science and technology-research journal. ISSN: 2299-8624. Volume: 12, Issue: 1, pp. 228-235.
3. **Caban, J.; et al**. 2015. Studies on operational wear of glycol-based brake fluid. Przemysl Chemiczny. ISSN 0033-2496. - Vol. 94, iss. 10.
4. **Figlusz, T.; Gnap, J.; Skrúcaný, T.; Szafraniec, P.;** 2017. Analysis of the influence of different means of transport on the level of traffic noise. In: Scientific journal of Silesian university of technology-series transport, vol. 97, 2017, ISSN: 0209-3324; DOI: 10.20858/sjsutst.2017.97.3
5. **Hockicko, P.; Trpišová, B.** 2013. Are students’ conceptions about automobile braking distances correct? In: Engineering Education Fast Forward 1973 – 2013: proceedings of the 41st SEFI annual conference, 16-20 September 2013, Leuven, Belgium. Brussels: SEFI, ISBN 978-2-87352-004-5.
6. **Kasanický, G.; Kohút, P.; Lukášik. M.** 2004. Impact dynamics theory for the analysis and simulation of collisions, Zilina: University of Zilina, EDIS, 350 pp, ISBN 80-8070-312-4
7. **Kubáňová, J.; Poliaková, B.** 2016. Truck driver scheduling of the rest period as an essential element of safe transport. In: Transport means 2016: proceedings of the 20th international scientific conference: October 5-7, 2016 Juodkrante, Lithuania. ISSN 1822-296X. Kaunas: Kaunas University of Technology. pp. 22-26.
8. **Rievaj, V.; et al**. 2013. Automobile and its dynamics (in Slovak), Zilina: University of Zilina, EDIS, 224 pp., ISBN 978-80-554-0627-5
9. **Skrúcany, T.; Šarkan, B.; Gnap, J.** 2016. Influence of aerodynamic trailer devices on drag reduction measured in a wind tunnel. In: Eksploatacja i Niezawodność = Maintenance and Reliability. ISSN 1507-2711, 18(1): 151-154.
10. **Šarkan, B.** 2013. Diagnostics of road vehicles: instructions for exercises (in Slovak). Zilina: University of Zilina, EDIS, 106 pp, ISBN 978-80-554-0799-9.
11. **Šarkan, B., Stopka, O., Gnap, J., Caban, J.** 2017. Investigation of Exhaust Emissions of Vehicles with the Spark Ignition Engine within Emission Control. TRANSBALTICA 2017: TRANSPORTATION SCIENCE AND TECHNOLOGY, Book Series: Procedia Engineering, Volume: 187, Pages: 775-782, DOI: 10.1016/j.proeng.2017.04.437.
12. Handbook of XL Meter™ Pro
13. SW PC Crash, 10.9, SW XL Vision™

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Pure Aloha Approximation to Mode S Transponder Throughput Modelling

T. Lipták[1], P. Lukeš[2], S. Pleninger[3]

[1]*Czech Technical University in Prague, Faculty of Transportation Sciences, Department of Air Transport, Horská 3, 128 03 Prague, Czech Republic, E-mail: liptatom@fd.cvut.cz*
[2]*Czech Technical University in Prague, Faculty of Transportation Sciences, Department of Air Transport, Horská 3, 128 03 Prague, Czech Republic, E-mail: lukespe3@fd.cvut.cz*
[3]*Czech Technical University in Prague, Faculty of Transportation Sciences, Department of Air Transport, Horská 3, 128 03 Prague, Czech Republic, E-mail: pleninger@fd.cvut.cz*

Abstract

An aeronautical surveillance infrastructure in technologically developed regions is primarily based on cooperative systems. A core part of the infrastructure consists of Secondary Surveillance Radars (SSR), Multilateration systems (MLAT) and an Automatic Dependent Surveillance-Broadcast (ADS-B). Due to the inherent nature of the cooperative technologies, the on-board transponders and the 1030/1090 MHz frequencies are shared among all the systems. The collective usage combined with growing air traffic and the necessity for extracting downlink airborne parameters using Mode S result in large demands on RF spectrum and on the on-board equipment. The increasing occupancy goes hand in hand with increasing probability of an interrogation interference. The prospect of a surveillance information loss highlights the need to analyse and possibly predict the behaviour of 1030/1090 MHz environment by air navigation service providers. This paper focuses on a plausibility of approximating the SSR Mode S (selective) interrogation sequences in multi-radar coverage to a Pure Aloha protocol which incorporates a mutual independence of radar systems and an interrogation retransmission. The feasibility of the approximation is evaluated using simulation of a typical interrogation sequence while analysing the Mode S transponder throughput. The Pure Aloha model parameters to fit the selected interrogation sequence are devised.

KEY WORDS: *Pure Aloha protocol, Mode S, Secondary Surveillance Radar, 1030/1090 MHz congestion*

1. Introduction

With a growing air traffic and a positive trend of a growth rate for the future years, there are large demands on already very congested airspace. The continuous strive for achieving reduced separation minima is conditioned upon fulfilling necessary surveillance requirements. For typical surveillance infrastructure consisting of Mode S Secondary Surveillance Radars (SSR), Multilateration systems (MLAT) and Automatic Dependent Surveillance-Broadcast (ADS-B), the ability to obtain all the surveillance information required is limited by a common use of 1030/1090 MHz frequencies.

Since a use of Mode A/C SSRs as an Air Traffic Control tool in 1960s there were known shortcomings caused by mutual interference effects or multipath phenomena [1]. The introduction of Mode S Monopulse SSRs have greatly decreased the required interrogation count, mitigated garbling and significantly reduced false replies unsynchronized in time (FRUIT). The following unexpected growth in air traffic and introduction of new technologies as ADS-B or TCAS systems without monitoring and predicting of 1030/1090 MHz congestion brought back an increase in FRUIT. Due to this fact and no near solutions of this problem, a possibility of surveillance information loss has greatly increased.

To prevent worsening of the current conditions and predict future 1030/1090 MHz congestion, a necessity for developing a tool to estimate the current situation and possibly analyse and predict future behaviour is needed. Principles of such a tool can be of a large variety but if an analytical or a statistical solution was found, it would decrease the necessity for creating large scale computer simulations based on exact algorithms.

In network and telecommunications there have been a great deal of possible protocols introduced some of which increase network capacity by a great margin. If we focus on Mode S Roll-Call interrogations from multiple radars to which a single aircraft is exposed to, we find that a Pure Aloha protocol might fit as a suitable model to the non-coordinated nature of interrogations from different radar.

2. Pure Aloha Assumptions and Model Fit Evaluation Method

The Pure Aloha protocol is extensively used in literature to approximate and analyse asynchronous interrogation patterns from multiple sources [2]. Although the interrogation and retransmission pattern of a single Mode S SSR is a deterministic process, the inability to obtain exact specifications of radars bounds even deterministic simulations to an approximation of a real-world scenario.

The Pure Aloha assumptions set in an aviation surveillance environment are following [3]:

1. If the SSR has an interrogation ready, it sends it immediately.

2. SSRs cannot generate new interrogations while transmitting.
3. If two interrogations from different SSRs collide both are retransmitted.
4. All interrogations have the same transmission length.
5. Interrogations and their retransmissions follow the Poisson distribution.

Hence, let λ represent an intensity of a Poisson process, τ interrogation length and $\rho = \lambda\tau$ normalized intensity. Then the mathematical model for throughput θ that follows the assumptions has a form as in Eq. 1.

$$\theta = \rho e^{-2\lambda\tau} = \rho e^{-2\rho} . \tag{1}$$

The first and the second assumption are generally true even for our situation. The third assumption states that if FRUIT happens, there is a zero probability of successful Defruiter processing. This is not generally true thus we can expect the vulnerable period to have a smaller size than 2τ which arises from this assumption.

The fourth assumption, although not always correct, might be easily approximated by a mean interrogation length of the different uplink formats. The last assumption is a significant requirement that is set upon the possibility of Pure Aloha approximation to Mode S Roll-Call interrogations. As it was mentioned earlier, the interrogation sequence is a deterministic model thus a possibility of an approximation of inter-interrogation times to an exponential distribution has to be assessed.

As a method for this evaluation, a software Monte Carlo simulation was developed incorporating a standard Mode S Roll-Call interrogation scheduling as specified by standards [4] and typical transponder occupancy behaviour with standardized values [5]. The simulation consists of 5 SSRs transmitting on a single aircraft where the number of interrogations sent and replies received is recorded. The initial interrogation from each radar is selected using random generated number respecting a uniform distribution within a typical dwell time of 0.03 s. To mitigate this initial time lag on the final results, the simulated real time was set to 10 seconds for each tested intensity value putting the random component to negligible 3‰.

If we return to Eq. 1, it can be pointed out that the only parameter that might be estimated is a multiplier by which the size of an interrogation is multiplied by so as to obtain the vulnerable period. Setting this parameter to α then we get Eq. (2).

$$\theta = \rho e^{-\alpha\rho} . \tag{2}$$

Due to the nonlinearity of this equation the best way to estimate α with a use of the data obtained from the Monte Carlo simulation is to apply an iterative nonlinear least squares algorithm where the initial value can be found by the linearization of Eq. 2 resulting in Eq. 3.

$$-ln\frac{\theta}{\rho} = \alpha\rho . \tag{3}$$

If we substitute $y = -ln\frac{\theta}{\alpha}$ then the Eq. 3 can easily be used in a linear regression model. Since the error metric of this linear regression model is not dependent just on θ, such an approach can be used solely for an initial value of the nonlinear least squares algorithm and not for the solution itself.

3. Results

First to evaluate the 5th assumption of Pure Aloha mathematical model, a modified version of the previously described Monte Carlo simulation was run. The simulation consisted of the same environment where only a single format was used (UF 4) and the Mode S transponder capability of responding was disabled resulting in a shutdown of subsequent processes comprising of the transponder processing, reply and recovery [5]. This enabled more thorough insight into the possibilities of approximating interrogations and retransmissions to the Poisson distribution. The obtained results can be seen in Fig. 1.
To evaluate how the model corresponds to larger normalized intensities the number of radars was increased up to 15. Other simulation parameters were kept the same as in the previous scenario. The related results of the simulation can be seen in Fig. 2.

For the evaluation of the the 3rd and 4th assumption, three simulation scenarios were run with the correct transponder behaviour and 5 SSRs interrogating. Each scenario differs in transmitted interrogation and reply formats. The first scenario uses only UF4 and DF4, the second UF20, DF20 and the third uses combination of UF4, UF20 interrogation with respective downlink formats. The interrogation intensity in the combined format scenario is distributed equally between the two. The results of these scenarios can be found in Fig. 3.

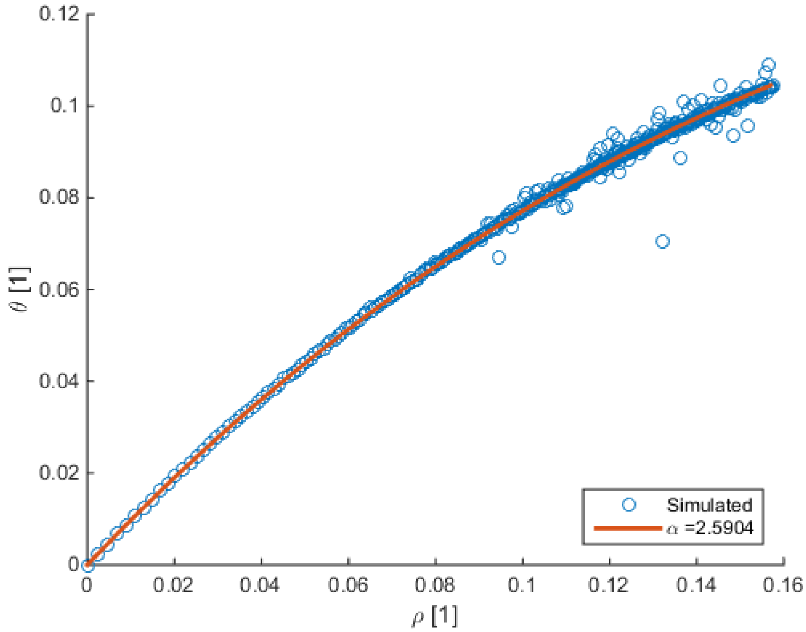


Fig. 1 Poisson distribution assessment - 5 SSRs

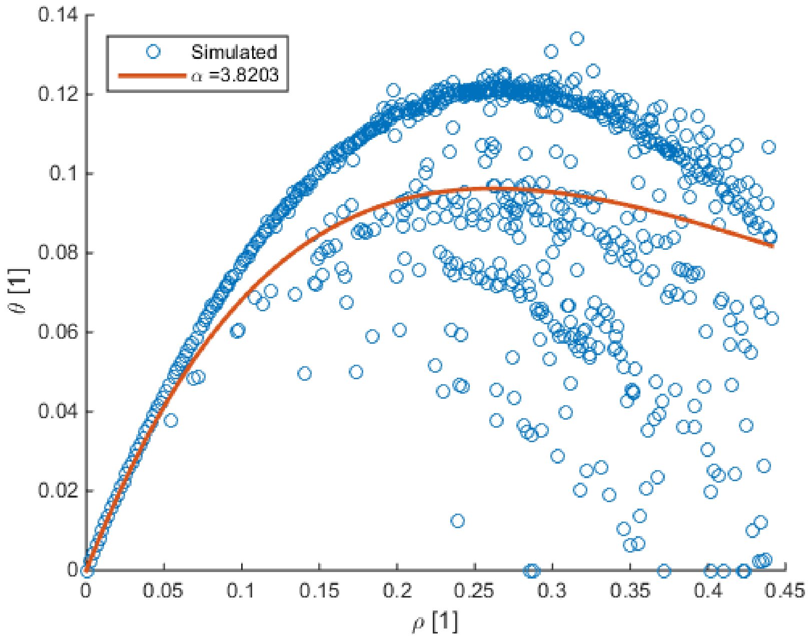


Fig. 2 Poisson distribution assessment - 15 SSRs

4. Discussion

As it can be seen in Fig. 1, due to the limited maximum intensity that each radar can send, caused by the geometry of the simulation environment, a maximum intensity and the Pure Aloha curve shape were not obtained. However, if we use the generated data to estimate the best fit of Pura Aloha mathematical model, we can see that the model fits, although with α = 2.5904. This scaled up vulnerable period does not entirely correspond with the 2τ and therefore inconsistent with the Pure Aloha protocol. Nevertheless, since the very nature of the inter-interrogation times is different, it indicates that a statistical evaluation of α parameter to tune the model might be possible.

As the results in Fig. 2 show, for large intensities the obtained data are very noisy. This could be so because the radars are transmitting close to their maximal intensities so the random initial interrogation time might cause the interrogations sequences to “set” in each other. If we look at the curve obtained by the estimated α parameter we can see that the it starts to differ early due to the noisy part of the data. Although this could be seen as a complete denial of the Pure Aloha model, it is very unlikely that an aircraft would be interrogated by 15 SSRs for a significant amount of time because of radar beam rotation. Even in the SSR cluttered environment as Central and Western Europe.

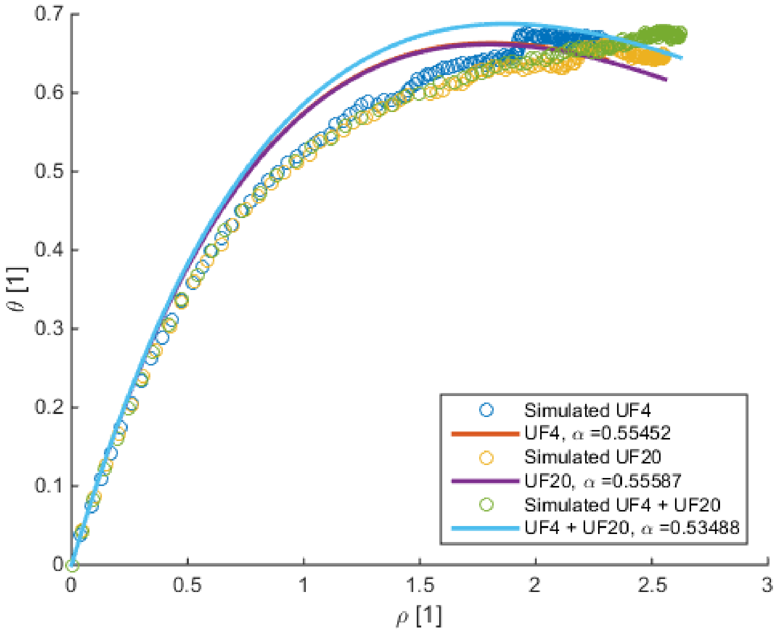


Fig. 3 Approximation to real-world scenarios

The results of the 3 scenarios with the correct transponder behaviour in Fig. 3 indicate that Pure Aloha model starts to diverge from simulation with increased complexity of transponder behaviour. The dissimilarities of the estimated model curve and the obtained data are mostly caused by the weak adaptability of the single parameter equation (Eq. (2)). Aside from this, if we focus on a value of estimated parameter α we can see, that it is close to $\frac{1}{2}\tau$. It is to be noted that in these three scenarios with full capability of transponder behaviour the τ does not strictly represent interrogation length but the length of the whole occupancy sequence of transponder processes which is used to calculate frequency capacity. In the second part of the occupancy sequence (processing, reply, recovery) only a single interrogation gets retransmitted if a collision occurs. Thus, we can expect the value of α to be shorter than τ yet longer than the transmission length of an interrogation. That is a necessary adjustment that has to be done to refine the 3rd assumption.

5. Conclusion

The possibility of modelling Mode S Roll-Coll interrogation sequence using Pure Aloha model approximation in multi-radar coverage was analysed. It could be seen that with increasing complexity of the transponder processing the estimated and simulated values started to diverge. Although the difference between mathematical model and simulated values could for some applications become unattainable there still might be use where the simplistic mathematical model of Pure Aloha with correctly selected α parameter would be beneficial.

References

1. **Stevens, M.C**. 1998. Secondary Surveillance. Radar Boston: Artech House. ISBN 08-900-6292-7.
2. **Seo, J.B.; Jin, H.** 2017. Optimally Controlled Pure ALOHA Systems for Wireless Sensor Networks. IEEE Communications Letters 21(11): 2460-2463, Nov. 2017. Retrieved from DOI: 10.1109/LCOMM.2017.2731314
3. **Pahlavan, K.; Levesque, A.H**. 2005. Wireless information networks. 2nd ed. Hoboken, NJ: John Wiley. ISBN 978-0-471-72542-8.
4. Doc 9684: Manual on the Secondary Surveillance Radar (SSR) Systems. 2004. 3rd ed. Montreal, Quebec, Canada: International Civil Aviation Organization.
5. DO-181E: Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/MODE S) Airborne Equipment. 2011. RTCA/DO-181E. Washington DC: RTCA.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Influence of Hydrogen Co-Combustion with HVO on Performance, Emissions and Combustion in the Compression Ignition Engine

R. Juknelevičius[1], S. Szwaja[2], S. Pukalskas[3]

[1]*Vilnius Gediminas Technical University, J.Basanavičiaus g. 28, LT-03224 Vilnius, Lithuania, E-mail: romualdas.juknelevicius@vgtu.lt*
[2]*Czestochowa University of Technology, Czestochowa, Faculty of Mechanical Engineering and Computer Science, ul. Dabrowskiego 69, 42-201 Czestochowa, Poland, E-mail: szwaja@imc.pcz.czest.pl*
[3]*Vilnius Gediminas Technical University, J.Basanavičiaus g. 28, LT-03224 Vilnius, Lithuania, E-mail: saugirdas.pukalskas@vgtu.lt*

Abstract

This study presents results from analysis of the combustion in the single cylinder compression ignition (CI) engine with the common rail injection system fueled with Hydrotreated Vegetable Oil (HVO) and hydrogen. The objective of the research, was to examine the impact of HES on combustion properties and combustion duration in the CI engine working at the constant speed of 965 rpm and with IMEP (Indicated Mean Effective Pressure) of low (345 – 380 kPa), medium (495 – 545 kPa) and nominal (652 – 692 kPa) loads. Hydrogen was used at amounts up to 40% hydrogen energy share (HES). Hydrogen was injected into the intake manifold, where it created homogeneous mixture with air. Tests were performed at both fixed and optimal injection timings. Results from experiments show that with increase of amounts of hydrogen into the engine, ignition delay time gets shorter that also affects main combustion phase and increases the in-cylinder peak pressure (p_{max}). The increase of *BTE* (brake thermal efficiency) was noticed, and decrease of *BSFC* (Brake specific fuel consumption) was registered with increase of hydrogen fraction. The supply of H_2 decreases engine emissions: smokiness, carbon dioxide and carbon monoxide. However, unburnt hydrocarbons increased with increase of HES to 10 – 15% and next decreased with further increase of HES. The hydrogen induction up to 10% HES decreased the NO levels. However with HES of more than 10%, NO level increased. The effect of hydrogen fraction on the combustion characteristics of the diesel - hydrogen mixture was validated by applying the AVL BOOST software.

KEY WORDS: *Hydrogen, Compression ignition engine, HVO, RCCI, Hydrogen – diesel*

1. Introduction

Interest in alternatives of fossil fuels is continuing to increase all over the world. This is motivated mainly by the following: concerns about greenhouse gas (GHG) emissions and global warming, a desire for renewable and sustainable energy sources, an interest in development of the local and more secure fuel supplies than that existing in politically unstable zones of the Globe [6], costly delivery of the raw material for fossil fuel, utilization of increasing bio-waste feed stocks.

The Environmental Protection Agency (EPA) together with increasing number of international and local authorities urges to introduce stronger regulations because ofcontinuous increase of the earth surface temperature and global warming. This change of the climate has disruptive consequences for ecosystems, agriculture, and coastal communities. The best evidence of warming effects is the warming of the oceans, followed by dramatic melting of glaciers and polar ice, increased extreme weather events, floods, tornadoes. Recently, scientists from the National Aeronautics and Space Administration (NASA) reported that carbon dioxide (CO_2) from anthropogenic actions continues to increase above levels have not been seen in hundreds of thousands of years [24]. Agreeing to this statement the International Energy Agency (IEA) informed that since the beginning of the Industrial Revolution in the middle of 19^{th} century, human activities increased by 44% the atmospheric concentration of CO_2, from 280 ppm to 403 ppm in 2016. Increase have been also noticed as follows: in the levels of the methane (CH_4): from 1570 ppb in 1980 to 1850 ppb in 2016 and the nitrous oxide (N_2O): from 300 ppb in 1980 to 330 ppb in 2016 [7]. In terms of CO_2 equivalents, the atmosphere in 2016 contained 489 ppm, of which 403 is CO_2 alone. The rest comes from other gases. The International Panel of Climate Change (IPCC) suggests that a constant concentration of CO_2 alone at 550 ppm would lead to an average increase of the Earth's temperature by ~3°C [38].

In 2015, global CO_2 emissions reached 32.3 $GtCO_2$, which is – 0.1 % in compare to the 2014. The year 2015 was the first year since the 1990s in which do not increased the global CO_2 emissions from fuel combustion whilst the global economy keeps growing [9]. Electricity and heat generation accounted for 13.56 $GtCO_2$, and transport, accounting for 7.75 $GtCO_2$. For transport, the 68% increase since 1990 was led by increasing emissions from the road transport which accounted 5.8 $GtCO_2$.

Revolutions in Arab countries, civil wars in the North Africa and Middle East, Iran nuclear crisis, sanctions of

US on Russia make concerns about the stability of the energy sources and force consumers to look for sustainable energy sources supplied by domestic suppliers. In fact, almost hundred years ago Germany was forced to employ own domestic energy sources, because Alliance powers after World War I, blocked access to the sources of fossil fuel of the defeated Germany. These circumstances influenced Germany to utilize it substantial coal reserves to refine syngas into liquid fuels. The process of the coal-to-liquid (CTL) or Fischer-Tropsch synthesis (FTS) discovered and the era of synthetic fuel began [39]. The overall process from original carbon source of the syngas to the FTS product named after the feedstock employed. The synthesis of the CTL developed by Fischer-Tropsch, was extended by gas-to-liquid – GTL, biomass-to-liquid – BTL [39], hydrotreated renewable diesel – HRD, hydrotreated vegetable oil – HVO [1, 15, 20, 22, 35] technologies.

The current alternative biomass based biofuels are first, second and third-generation. Their use may improve the emissions levels, because of the lower C/H ratio of biofuels causes the reduction of CO_2 emission. Most biofuels today produced from commonly available, edible feedstock and classified as first-generation. They can offer some CO_2 benefits and can help improve domestic energy security [27, 32]. Biofuels produced from second-generation biomass does not compete with food production, however high raw material costs are still an issue in making it processes economically attractive [17]. Biomass (vegetable oils and animal fats) consist of a mixture of triglycerides, i.e. esters of glycerol and unsaturated fatty acids. Esterification of triglycerides with alcohol (methanol) in presence of catalyst, gives a mixture of fatty acid methyl esters (FAME) and glycerol, which also considered as engine fuel [14]. FAME usually referred to as conventional biodiesel. The alternative to the esterification of triglycerides is the hydro treating of triglycerides. During this process, the HVO (also known as Renewable diesel fuel or Green Diesel) is produced of the same triglyceride, feedstock used to produce FAME or Rapeseed Methyl Ester (Fig. 1). However, FAME and HVO are the different products, with different chemical structure and physical properties.

The Finish scientists together with Neste Corporation developed the modern, renewable, oxygen-free, low-emission diesel fuel NExBTL (Neste's trademark for HVO process) produced from second-generation feeedstock's: palm, soybean, rapeseed oils, as well as waste and residue fat fractions coming from food, fish and slaughterhouse industries [10]. The composition of NExBTL is similar with that of GTL and BTL diesel fuels made by FTS [1]. Therefore, use of HVO in CI engine reduces CO, THC, NO_x emissions, and soot. NExBTL has excellent cold starting and clean combustion properties due to high cetane number and low C/H ratio, does not create deposits in the crankcase [20]. The NExBTL is fully saturated paraffinic hydrocarbon fuel with chemical-physical properties similar to the petroleum diesel fuel.

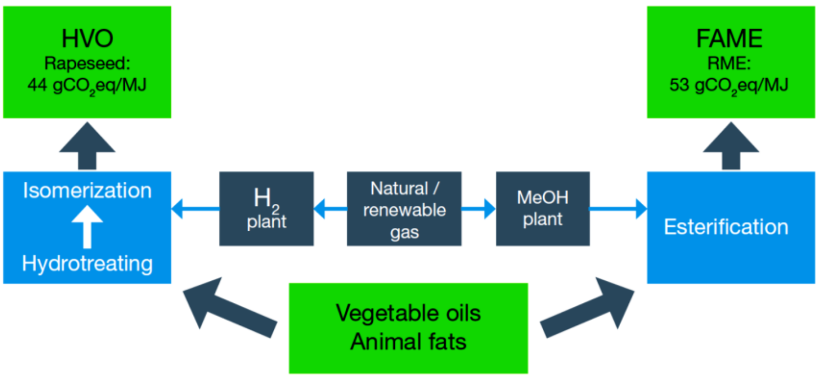


Fig. 1 The transesterification and hydrotreating processes with inputs and outputs for biofuel (HVO and FAME) production with default well-to-tank GHG values [18].

During production of HVO and NExBTL, hydrogen is used to remove the oxygen from the vegetable oil, after which catalytic isomerization into branched alkanes is done to get paraffinic hydrocarbons [26]. During the hydro treating of triglycerides at the first step, free fatty acids formed from the triglyceride molecules in presence of hydrogen [35]. One mole of propane and three moles of oleic, palmitic, and linoleic fatty acid are formed, respectively:

Trigliceride *Free fatty acid (oleic, palmitic, linoleic)*

$$C_3H_5\left(C_{18}H_{33}O_2\right)_3 \xrightarrow{3H_2} C_3H_5\left(C_{18}H_{35}O_2\right)_3 \xrightarrow{3H_2} 3C_{17}H_{35}COOH + C_3H_8$$

In the second step, hydrogenation takes place to saturate the oleic and linoleic acids, because the side chain of palmitic acid is already completely saturated. Then, the three common reported reactions to eliminate oxygen may occur:

− Decarboxylation: $C_{17}H_{35}COOH \rightarrow C_{17}H_{36} + CO_2$
− Decarbonylation: $C_{17}H_{35}COOH + H_2 \rightarrow C_{17}H_{36} + H_2O + CO$
− Hydrodeoxygeneration: $C_{17}H_{35}COOH + 3H_2 \rightarrow C_{18}H_{38} + 3H_2O$

Decarbonylation and decarboxylation form hydrocarbons having one carbon atom less than the parent free fatty acid (FFA) whereas hydrodeoxygenation removes the oxygen atom keeping the same carbon atoms as in the original

FFA. In this way, the fully saturated hydrocarbon paraffins are comprised in the range of C_{15} – C_{18}. The properties of the HVO along with petrol diesel and hydrogen presented at the Table 1.

Table 1

Fuel properties

Properties	**Test method**	**Petrol Diesel**	**NExBTL (HVO)**	**Hydrogen**
Chemical formula	–	$C_{10}H_{22}$ – $C_{15}H_{32}$	$C_{15}H_{32}$ – $C_{18}H_{38}$	H_2
Composition (wt), %	–	86.5 C, 13.5 H	84.8 C, 15.2 H	100
Density, kg/m³ at 15°C and 1.01 bar	EN ISO12185	835.3	779.4	0.08985
Molar mass, g/mol	–	142.3 - 212.4	212.4 - 254.5	2.016
Lower heating value (wt), MJ/kg	ASTM D4809	42.5	43.7	120
Lower heating value (vol), MJ/Nm³	ASTM D4809	36350	34092	10.7
Stoichiometric air-fuel ratio (wt basis), kg/kg	–	14.5	14.9	34.3
Stoichiometric air-fuel ratio (vol basis), Nm³/Nm³	–	10093	9678	2.6
Heating value of stoichiometric mixture (wt), MJ/kg	–	2.74	2.75	3.40
Heating value of stoichiometric mixture (vol), MJ/Nm³	–	3.60	3.52	3.00
Air–fuel equivalence ratio (λ)	–	0.82 – 12	–	0.14 – 10
Auto ignition temperature at STP,°C	–	~ 250	~ 210	585
Flammability limits at NTP (vol%)	–	0.6 – 7.5	–	4 – 77
Laminar flame speed, m/s at NTP	–	0.3	–	2.65 – 3.25
Kinematic viscosity, mm²/s at 40°C	EN ISO3104	2.847	2.867	118
Aromatics (wt), %	EN 12916	23.2	0.3	–
Cetane number (CN)	ASTM D6890	54.6	74.3	5 – 10
Carbon to hydrogen ratio (C/H)	–	6.4	5.6	–

The HVO fuel is a low aromatic, light fraction hydrocarbon in comparison to the petrol DF, has a higher lower heating value 43.7 MJ/kg, because of the fact that hydrogen content of HVO is 15.2% (wt) compared to 13.5% (wt) of standard DF (Table 1). The CN of HVO is much higher (74.3) as well in comparison to petrol DF (54.6), because of its nature as a mixture of *n*- and *i*-paraffins [18]. High CN is the advantage for NO_x emissions and the lower carbon content of this fuel (5.6), make the combustion less susceptible for soot formation.

The results of the dynamometer and on road vehicle tests performed by Sugiyama et al. [36], revealed that the high CN and the low aromatics fraction of the HVO reduced HC and PM emissions, and is capable to improve BSFC. Use of HRD by Singh et al. [34] showed the reduction of particulate matter (PM), CO and HC emissions as well as BSFC, when compared to petrol DF. However, NO_x increased by 26%. The results performed by Ewphun et al. [12] showed that increasing HVO fraction at the fuel content decreased the ignition delay, flame temperature, soot concentration and NO_x concentration. However, with decrease of the oxygen concentration by EGR, effected contrariwise. A combination of EGR with supercharger resulted in decreased flame temperature, ignition delay and soot concentration, compared to sole EGR conditions. During the tests performed by Pirjola et al. [26], the substitution of DF with HVO, the emissions of NO_x reduced by 20% and PM by 44%. Bhardwaj et al. [7] noted that the HVO fuelling resulted in about 50% reduction in smoke emissions and 43% reduction in gravimetric PM flow. These and other studies [1, 11, 19, 21, 23, 25] conducted with the CI engines fueled with HVO showed that HVO reduce NO_x, soot emissions and deposit formation in the cylinder, therefore HVO has beneficial fuel for the CI engine.

Subsequent studies of the CI engine with hydrogen addition [2, 5, 6, 29, 31, 33, 37, 41] show that emissions and performance parameters are dependent on injection timing of DF, its duration, *BMEP*, *MFB* and engine speed. The hydrogen being no carbon fuel can reduce the CO and PM emissions, and provide high flame propagation, because of extremely low ignition energy so that provides higher brake thermal efficiencies.

Tests carried out with amounts of HES = 5% [37], shortens the CI engine ignition lag and, decrease the rate of pressure rise. With a hydrogen share of 5 – 15%, the entire combustion duration does not change significantly, but with hydrogen share of 15% p_{max} increased. With HES of 17%, the combustion knock starts and with HES of 25%, the fast combustion accompanied by combustion knock.

Experiments carried out on the CI engine [2] with petrol DF blended with 20% of RME (vol fraction) and different hydrogen energy fractions (HES) 0 – 5%, revealed the lower engine performance, efficiency, and emissions except the NO_x, which slightly increased. Addition of hydrogen to the fuel blend, the CO emissions, smoke, and total unburned hydrocarbon emissions (THC) decreased, while the NO_x kept the same increasing trend. The addition of hydrogen has not a significant effect on ignition delay.

During the investigation [29] performed on a diesel – generator, hydrogen was supplied with HES of 5 - 24% to the diesel – biodiesel (7%) blend (B7). With increase of the HES, CO_2, CO and HC emissions decreased. But the emissions of nitrogen oxides (NO_X) increased due to the increase of the in-cylinder temperature. There was also noticed an increase of the peak pressure and heat release rate, since B7 ignition delay was reduced due to increase of the HES.

The petrol DF tested with addition of 7% FAME on a CI engine with EGR [6]. No significant increase of NO_x was observed at each test conditions; however, HES of 25% caused a reduction of p_{max} and decrease by 22% of CO_2 emission at the lowest load and middle speed.

These reviewed experiments were performed on of the CI engine, either with sole HVO, or with addition of hydrogen to the petrol DF or FAME fuel blends. There are gaps in knowledge dealing with hydrogen co-combustion with HVO in the CI engine. In fact, the high reactivity fuel – HVO (high cetane number) coupled with the low reactivity fuel – hydrogen (low cetane number), is well suited for the reactivity controlled compression ignition (RCCI) strategy. RCCI is a dual fuel combustion technology that uses in-cylinder fuel blending with at least two fuels of different reactivity. The process involved in RCCI includes the introduction of a low reactivity fuel (H_2) into the cylinder to create a homogeneous air-fuel mixture. The high reactivity fuel (HVO) then injected directly into the combustion chamber [28]. The large difference of reactivity between the two fuels (HVO and H_2) can optimize the combustion phasing, duration and extend the operable load range while sustaining low smokiness and high thermal efficiencies [8].

The purpose of this research was to reveal the effects of HES on the performance efficiency, combustion phases and toxic exhaust emissions produced by a CI engine operating at constant speed, under RCCI combustion strategy, over three ranges of IMEP: low (345 – 380 kPa), medium (495 – 545 kPa) and nominal (652 – 692 kPa).

2. Experimental Set-up and Procedure

Tests were performed at the Institute of Thermal Machinery of Czestochowa University of Technology, in Poland. The single cylinder stationary compression ignition engine Andoria S320 equipped with the high pressure common rail fuel pump Bosch CR/CP1S3 driven by the 2.2 kW electric motor GL-90L2-4. The other electric motor was used as the starter for the CI engine. After starting up the CI engine, it delivers energy by two driving V-belts to a power generator. The engine was set to operate at the constant speed of 965 rpm ± 0.83%. The generated electric power was supplied to the power grid and was measured. The technical specifications of the test engine are given at the Table 2.

Table 2

Technical specifications of the test engine Andoria S320

Parameter	**Value**
Number of cylinders	1
Bore diameter, mm	120
Piston stroke, mm	160
Displacement, cm^3	1810
Compression ratio	17
Rated power, kW/HP	13.2/18
Rated speed, rpm	1500
Peak torque, Nm	84.4
Peak torque speed, rpm	1200
Length of connecting road, mm	275
Intake valve opening	23° BTDC
Intake valve closing	40° ABDC
Exhaust valve opening	46° BBDC
Exhaust valve closing	17° ATDC

Each experiment was conducted at the various *IMEP* (Indicated Mean Effective Pressure). The *IMEP* managed by changing the liquid and gaseous fuel (H_2) supply to the combustion chamber. The low reactivity fuel – hydrogen supplied together with air into the intake manifold. In cylinder, homogeneous air – hydrogen mixture under the elevated heat and pressure self-ignited by injected high reactivity HVO, following the RCCI combustion strategy. The consumption of HVO measured by stopwatch. Hydrogen was supplied into the engine intake manifold out of the balloon with a one-stage pressure regulator to reduce its pressure to 1 bar, which was the pressure of the hydrogen gas supply line. A firebreak valve was installed just upstream of the air intake manifold to prevent flashback phenomenon. The completely experimental installation presented at the Fig. 2.

Pollutants in the exhaust gas were analyzed using *Bosch* and *Maha* (smoke) analyzers. In-cylinder pressure (*p)* fixed by piezo sensor *Kistler* 6061B installed instead of the preheating plug. The crank angle (CA) fixed by encoder *Kistler* type 2612C. The data acquisition converter *Measurement Computing Corporation* PCI-DAS 6036 used in line with PC software *SAWIR* – System of the Indicator Chart on Real Time Analysis). Software InstalCal installed to the PCI-DAS 6036 converter for calibration and test as well as self-calibration of the analog input and analog output lines are available. Data acquisition application was controlled by the software SAWIR, developed using the programming environment Delphi 6.0 of Windows operating system.

The HVO was tested during this experimental study. Tests of the HVO were performed under LL of

IMEP = 344.9 – 371.7 kPa, ML of *IMEP* = 494.8 – 538.5 kPa and NL of *IMEP* = 645.8 – 691.5 kPa. As the presence of hydrogen effects the combustion duration, the start of diesel injection timing φ, during tests of hydrogen – biofuel mixture was set at the fixed position, enabling to compare and analyze several MFB profiles at various HES.

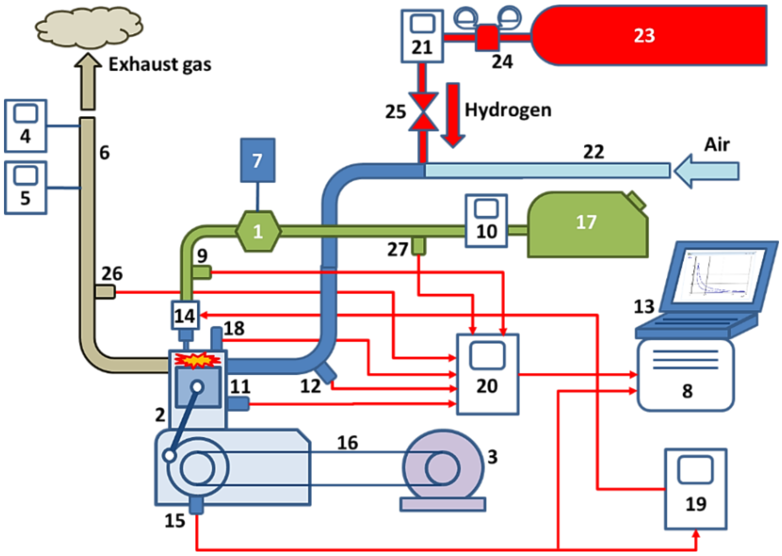


Fig. 2 Experimental set-up. *1* – Diesel Fuel (DF) pump, *2* – CI engine, *3* – Generator, *4* – Smoke analyser, *5* – Emission analyser, *6* – Exhaust pipe, *7* – DF pump drive el. engine, *8* – Data acquisition system, *9* – DF pressure sensor, *10* – DF flow meter, *11* – Engine temp. sensor, *12* – Inlet air temp. sensor, *13* – PC – SAWIR, *14* – DF common rail injector, *15* – CA encoder, *16* – Drive belt, *17* – DF tank, *18* – In-cylinder pressure sensor, *19* – DF injection controller, *20* – Amplifiers & A/D converters, *21* – Hydrogen flow meter, *22* – Air intake pipe, *23* – Hydrogen balloon, *24* – Hydrogen one-stage pressure regulator, *25* – Hydrogen firebreak arrestor, *26* – Exhaust gas temperature sensor, *27* - DF temperature sensor

The injection timing φ_1 for HVO operation (Table 3, test no. 1) was determined at the position of 50% MFB, which corresponds to the peak of indicative pressure in cylinder. This position was set within the 8 – 12 deg CA. The injection timing φ_2 (Table 3, test no. 2) was determined with the lowest HES = 13%, again at the combustion of 50% MFB within the range of 8 – 12 deg CA. The same injection timing φ_2 was used for the rest of tests with hydrogen fractions of 22% and 29%. Incidentally $\varphi_1 = \varphi_2$, with pure biofuel (HES = 0%) and with supply of hydrogen. This circumstance enables to compare emissions and performance parameters, within the whole range of HES; starting form HES = 0% to the highest values of HES tested during the experiment. At the ML operation φ_1 = 24 deg (Table 3, test no. 3) was determined at the HES = 0%, and injection timing was fixed at φ_2 = 24 deg with change of the HES as following: 13%, 25%, 30%. At the NL operation φ_1 = 28 deg was determined at the HES = 0%, and φ_2 = 28 deg was fixed with change of the HES as following: 12%, 24%, 29%.

Table 3

Injection timing and IMEP at various composition of combustible mixture

Test no.	Composition of combustible mixture	SOI φ, before the top dead centre (BTDC)	Loads
1	HVO + H_2 0%	φ_1 = 18°	Low Load (LL)
2	HVO + H_2 (13 – 40%)	φ_2 = 18°	Low Load
3	HVO + H_2 0%	24°	Medium Load (ML)
4	HVO + H_2 (13 – 30%)	24°	Medium Load
5	HVO + H_2 0%	28°	Nominal Load (NL)
6	HVO + H_2 (12 – 29%)	28°	Nominal Load

The Bosch CR/CP1S3 fuel pump supplies the liquid fuel (HVO) to the single common rail Bosch diesel injector 0445110076, managed by electronic control unit. The start of injection (SOI) was adjusted by electronic control unit which controls the injector-needle-valve lift. The start of combustion (SOC) was considered at the CAD at which the curve of the rate of heat realize (ROHR) crosses the zero line. The curve of ROHR was determined by PC software *SAWIR*. The 200 single-cycle in-cylinder pressure diagrams versus CAD were recorded for every load and HES. The ROHR was calculated by using averaged 200 combustion cycles of the in-cylinder pressure-data and cylinder volume over CAD.

3. Analysis of the Results and Discussion

The main topic of the presented research was the impact of HES on combustion properties and combustion duration of the CI engine operating under the RCCI combustion strategy, at the fixed injection timing at three *IMEP*.

In-cylinder maximum pressure curves for various hydrogen fractions are provided at the Fig. 3. The increase trend of in-cylinder maximum pressure was noticed with increase of HES more than 12% within all range of loads. The increase of in-cylinder maximum pressure at LL was negligible (1%), at ML, it was 9% and at NL, increase of 14% was measured. The negligible influence of hydrogen fraction at the LL and partially at the ML can be explain by the low volume fraction of the hydrogen in the combustion chamber. The volume fraction of H_2 at LL tests are within the range of 1.38 – 2.87%, which is below the lower flammability limit of hydrogen – 4% (Table 1) and the combustion was not intensified by presence of the hydrogen. The low volume fraction of H_2 at the LL has not significant influence in compare to the ML and NL conditions. The lean hydrogen – air mixture does not support the flame propagation and results in rather low hydrogen combustion efficiency [30]. When this boundary was exceeded, with HES more than 12 – 13% at the ML and NL, the combustion became more intensive, especially at the premixed phase and in-cylinder p_{max} increased.

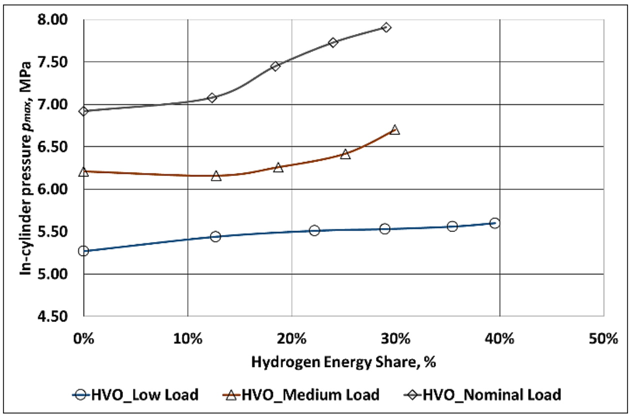


Fig. 3 In-cylinder max pressure p_{max} vs. HES

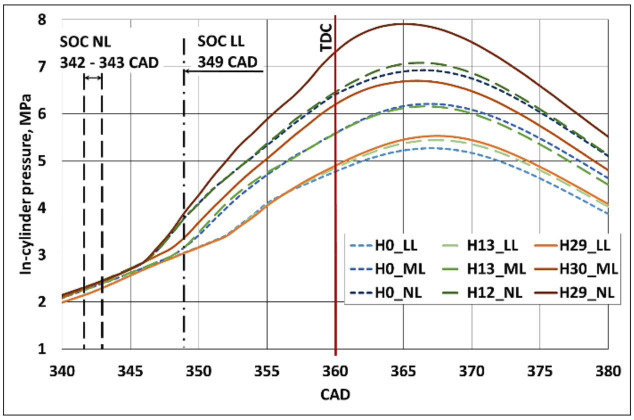
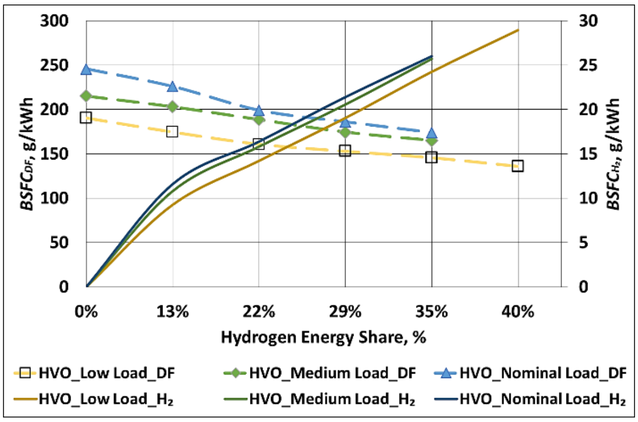


Fig. 4 In-cylinder pressure history at various loads and HES

The in-cylinder pressure data is helpful in verifying this phenomenon, presented at the Fig. 4 with the positions of SOC of corresponding mixtures. The SOC at the LL occurs at the 349 CAD, at the ML and HES 0 – 25% at 345 CAD, at the ML and HES 30% at 345 CAD, at the NL and HES of 0 – 24% at 343 CAD, at the NL and HES of 29% at 342 CAD. Very slight influence of HES, was noticed at the LL (HES = 13 – 29%) and ML (HES = 13%). The more tangible impact of HES was noticed at ML (HES = 30%) and NL (HES = 29%).

After the analysis of the AVL BOOST simulation data it was revealed, that the hydrogen fraction affects the combustion intensity of the fuel mixture at the early stage of combustion process, only at ML and NL. Due to the very intensive combustion after the SOC, the combustion intensity parameter decreased at ML and NL with increase of HES (Fig. 16). The early stage of the combustion of 0 – 10% MFB has the significant influence on the further combustion process. The combustion at that stage has mainly quasi-laminar character [16] and high laminar flame speed of hydrogen, homogeneity of the mixture can stimulate the combustion process and heat release. However, it depends on the volume fraction of hydrogen and it lower flammability limit.



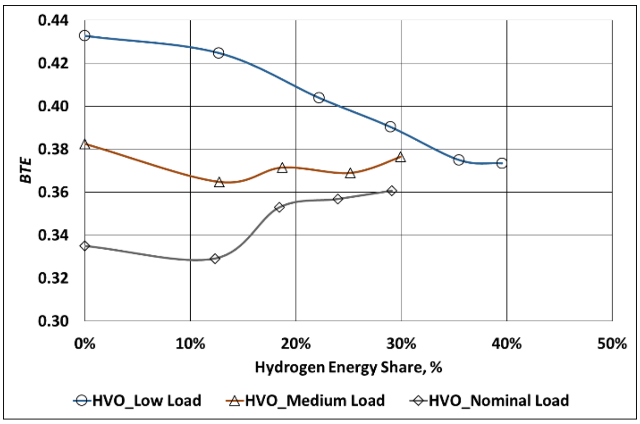


Fig. 5 $BSFC_{DF}$ and $BSFC_{H_2}$ vs. HES

Fig. 6 BTE vs. HES

The *BSFC* presented at the Fig. 5, considering the RCCI dual fuel combustion technology. It means that $BSFC_{DF}$ and $BSFC_{H_2}$ has been evaluated. With increase of HES the $BSFC_{H_2}$ increased linearly, because the hourly heat value of the hydrogen directly correlated with HES. The $BSFC_{DF}$ decreased with increase of HES. The higher $BSFC_{DF}$ at the ML and NL can be attributed mainly to the higher mass flow rate of liquid fuel – HVO. The total *BSFC* decreased by 17.5% at NL, by 14% at ML and by 9% at LL with increase of HES, because of increase of the mass flow rate of hydrogen. The decrease of the total fuel mass flow rate by 10 – 13% was noticed at the ML and NL and did not change at the LL with increase of HES. The substitution of HVO by hydrogen makes positive affect on total *BSFC*.

The *BTE* changed with increase of the HES in the following way: it decreased at LL by 12%, almost did not changed at the ML and increased by 9% at the NL (Fig. 6). As it was mentioned before, the presence of the hydrogen affects the combustion intensity only at ML and NL. The lower heating value of the fuel mixture did not change, with increased engine load, and therefore did not make any significant effect on *BTE*. The biggest influence on the *BTE*, was made by increased mass flow rate of the hydrogen (Fig. 5) as the response to the decreased total fuel mass flow rate by 10 at the ML and by 13% at the NL.

The NExBTL used during the test, has 12.5% lower C/H ratio in compare to the petrol DF (Table 1). The increased hydrogen increment rate caused the decrease of C/H ratio and that causes the reduction of CO and CO_2 emission

(Figs. 7-8). (CO) in the exhaust gas as well as reduction of its smokiness [2, 6, 29].

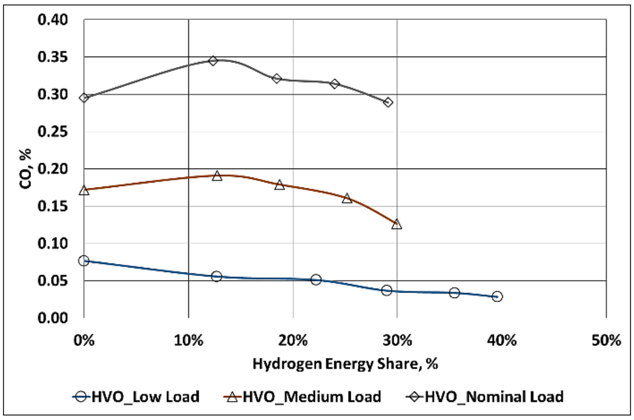


Fig. 7 CO emission vs. HES

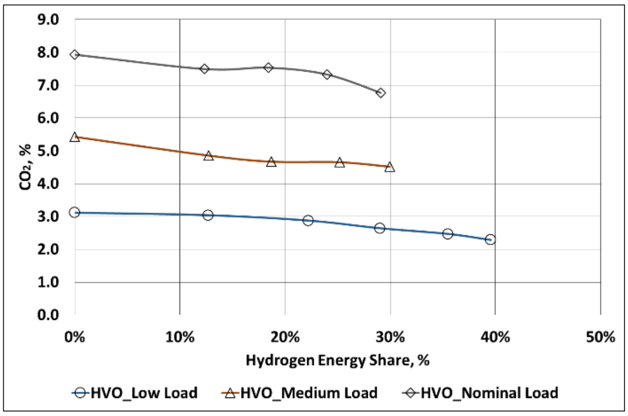


Fig. 8 CO_2 emission vs. HES

The decrease in smokiness as shown in Fig. 10, confirms the statement that with increase of HES the air and fuel mixture makes better premixed. While the increase of hydrogen fraction in the mixture enhances the temperature and thus contributes the conditions for the formation of the NO (Fig. 9). The HES at the low load does not enhance the NO formation within the test range up to 40% HES. The highest increase of exhaust gas temperature with increase of HES, was measured within the range of 72 – 75ºC at low load and medium load, while at nominal load it was 119ºC. This increase of temperature determines the increase of NO from 770 ppm with HES = 0% to 1040 ppm with HES of 29% [6, 29].

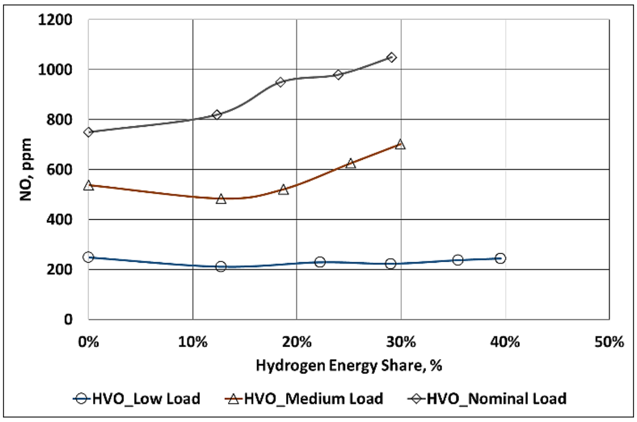


Fig. 9 The dependence of NO on loads and HES

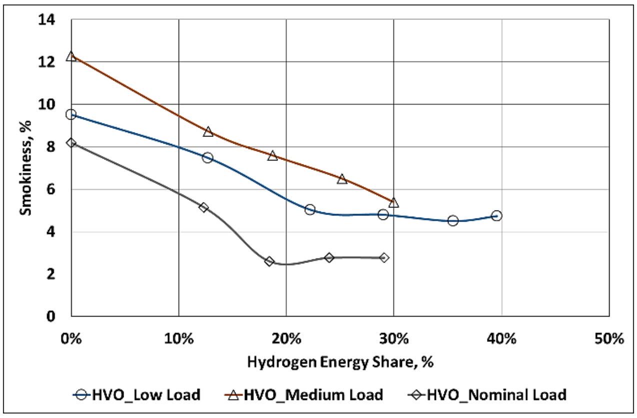


Fig. 10 The dependence of CO on loads and HES

The MFB was calculated as the normalized cumulative heat release. The combustion duration of CA 0 – 10 and CA 10 – 90 was calculated at each *IMEP* and with each hydrogen fraction for HVO according to the MFB profiles.

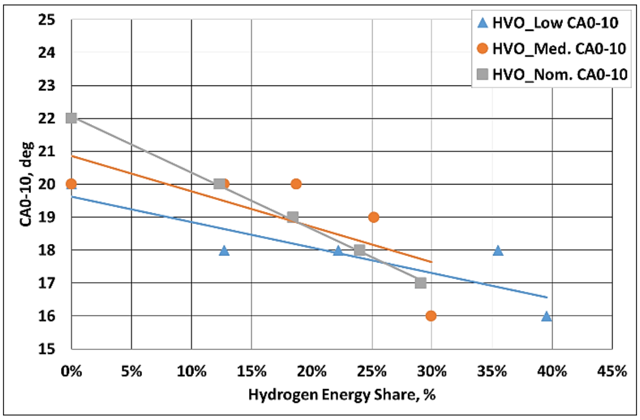


Fig. 11 The combustion delay 0 – 10% MFB at various HES and test loads

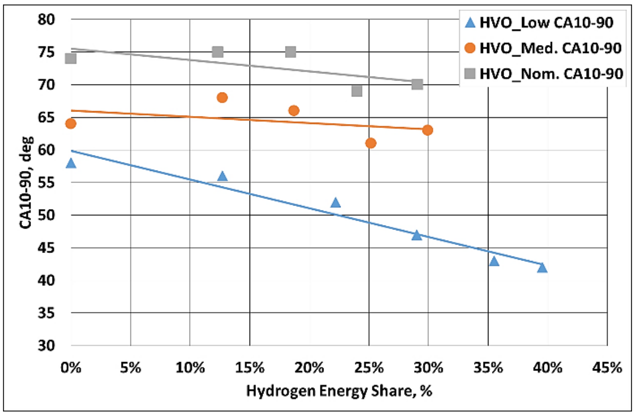


Fig. 12 The combustion delay 10 – 90% MFB at various HES and test loads

The increase of HES shortens the ignition delay (lag) expressed by the initial combustion duration of CA0–10 (Figs. 11 and 12) due to the high premixed combustion rate and impact of higher laminar speed of hydrogen flame. Increase of hydrogen fraction also reduces the main combustion duration CA10–90 (Figs. 12 and 13) which was accelerated by the first combustion phase CA0–10.

4. Simulation Using AVL BOOST Software

AVL BOOST is the simulation software of engine cycles and gas exchanges that enables to build an engine model by selecting elements from a toolbox (Fig. 13). These elements include cylinders, injectors, air filters, catalysts, intercoolers, turbochargers etc. connected by pipe elements [4]. This AVL BOOST platform provides possibility to do advanced engine simulation in terms of cycle simulations, beneficial possibility of performing co-simulation with other simulation software and possibility of relatively easy implementation of user-defined models [3]. The AVL BOOST program used a two-zone combustion model [4]. An open thermodynamic system has been analysed with the exchange of the mass and energy with other engine systems.

The intensity of heat release during the working cycle was determined using [13] the Wiebe heat release function:

$$\frac{dx}{d\varphi} = a\frac{m_v+1}{\varphi_C}\left(\frac{\varphi}{\varphi_C}\right)^{m_v} e^{-a\left(\frac{\varphi}{\varphi_C}\right)^{m_v+1}},$$

where $dx = \frac{dQ}{Q}$; Q – cyclic heat release rate; φ – crank angle from SOC; φ_c – CD; m_v – combustion intensity shape parameter of the Wiebe function; a – efficiency parameter of the Wiebe function. For a CD corresponding to 0 - 99.9% MFB a = 6.9078 [40].

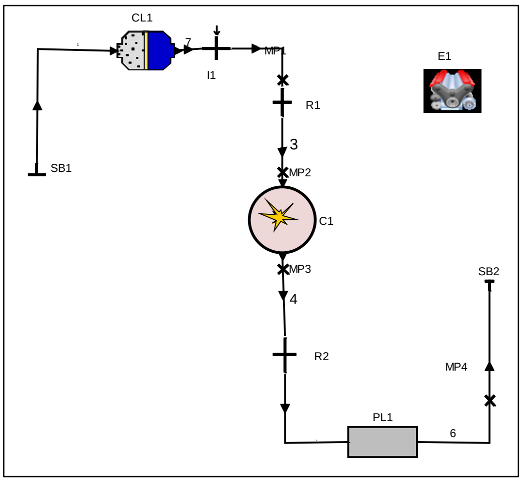


Fig. 13 The AVL BOOST engine module: I1 – H_2 injector; R1-2 – restrictors; SB1-2 – system boundaries; PL1 – exhaust manifold; CL1 – air cleaner; MP1-4 – measuring points; C1 – engine cylinder.

The following data was set for the simulation: bore, stroke, compression ratio, clearance volume, length of the connecting road, number of strokes, volumes of intake and exhaust manifolds, engine speed, *BMEP*, SOC (start of

combustion), CD, combustion intensity shape parameter m_v, *LHV* (lower heating value) of fuels, mass flow rates of DF, hydrogen and air. The simulation was performed at LL, ML and NL.

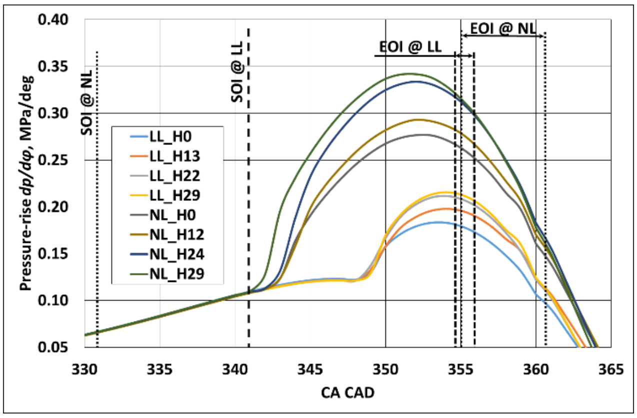


Fig. 14 Pressure-rise history at various loads and HES

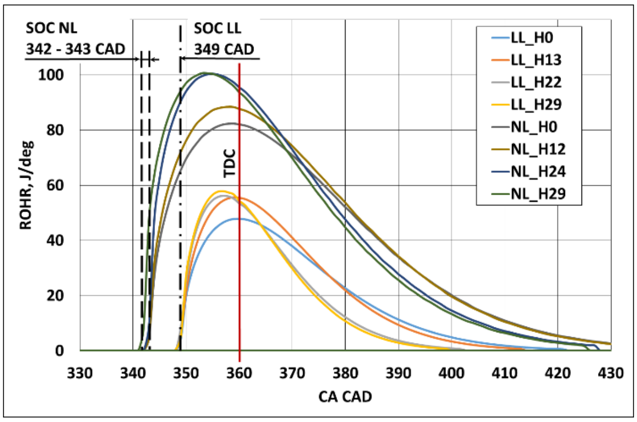


Fig. 15 ROHR history at various loads and HES

As observed from Figs. 14-15, there is significant difference in SOC with various HES and loads investigated. The auto ignition delay at NL was shorter (and SOC was earlier) by 1.5 CAD at HES = 29% in compare to the HES = 13 – 22 CAD (Fig. 14). The influence of HES at the LL has not been expressed as it was at NL, because the low volume fraction of the hydrogen in the combustion chamber. As mentioned before, the volume fraction of H_2 at LL tests are within the range of 1.38 – 2.87%, which is below the lower flammability limit of hydrogen – 4% and the combustion has not intensified by presence of the hydrogen.

The evidence of HES influence was the ROHR, which increased by 22 % at NL and HES of 24 – 29 % (Fig. 15). The ROHR at LL increased by 21 % with HES of 13 – 29%.

The shape parameter decreased from 0.52 at LL to 0.39 at NL with HES of 29% (Fig. 16). High intensity combustion occurs after the SOC with increase of HES. However, hydrogen fraction affects the combustion intensity of the fuel mixture only at ML and NL. As depicted in Fig. 17, modeled combustion is getting shorter with higher amounts of hydrogen injected.

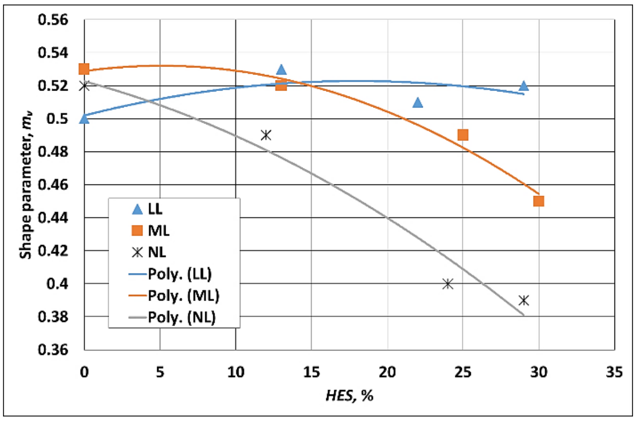


Fig. 16 The combustion intensity shape parameter m_v of the Wiebe function and it trend lines at the various HES

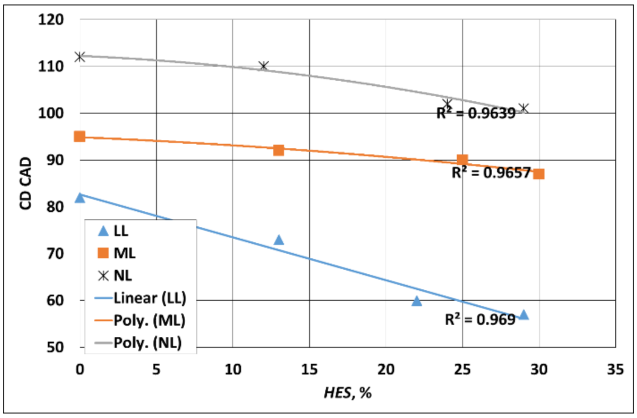


Fig. 17 The CD and it trend lines at the various HES

5. Conclusions

The main following conclusions can be drawn from the presented analysis:

− Adding hydrogen by port fuelled strategy to the CI engine fuelled directly with HVO is found as the effective way in improving engine performance and reduce toxic exhaust emissions.

− Hydrogen was added at amounts from 5 to 30% by energy to the entire combustible charge. 10-20% hydrogen addition was found as optimal percentage with respect to overall toxic emissions. However, *BTE* increases remarkably, while HES exceeds 20%.

− Hydrogen addition influences combustion phases: main combustion phase and ignition delay time. As observed, ignition delay expressed by CA0-10 was changed from 22 to 17 CAD at nominal load. This is significant difference, which requires injection timing to be modified to optimal value. CA10-90 is also shorter with HES increase, that makes combustion closer to constant volume conditions, what leads to increase in engine thermal efficiency.

− Modeling works confirmed usability of AVL software for verifying several hypothetical assumptions to

theoretical analysis.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691232 — Knocky — H2020-MSCA-RISE-2015/H2020-MSCA-RISE-2015.

The results of the research obtained by using a virtual internal engine simulation tool AVL BOOST, acquired by signing the Cooperation Agreements: AVL Advanced Simulation Technologies – Faculty of Transport Engineering of Vilnius Gediminas Technical University, and AVL Advanced Simulation Technologies – Institute of Thermal Machinery of Czestochowa University of Technology.

References

1. **Aatola, H.; Larmi, M.; Sarjovaara, T.; Mikkonen, S.** 2008. Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel: Trade-off between NOx, Particulate Emission, and Fuel Consumption of a Heavy Duty Engine. SAE Technical Paper 2008-01-2500. 12 p.
2. **Aldhaidhawi. M.; Chiriac, R.; Bădescu, V.; Descombes, G.; Podevin, P.** 2017. Investigation on the mixture formation, combustion characteristics and performance of a Diesel engine fueled with Diesel, Biodiesel B20 and hydrogen addition, International Journal of Hydrogen Energy 42: 16793-16807.
3. **Alqahtani, A.; Shokrollahihassanbarough, F.; Wyszynski, M.L.** 2015. Thermodynamic simulation comparison of AVL BOOST and Ricardo WAVE for HCCI and SI engines optimisation, Combustion Engines 161(2): 68-72. ISSN 2300–9896.
4. AVL BOOST v 2011.2. 2011. AVL BOOST Users Guide, Graz, Austria. 297 p.
5. **Baltacioglu, M.K.; Arat, H.T.; Ozcanli, M., Aydin, K.** 2016. Experimental comparison of pure hydrogen and HHO (hydroxy) enriched biodiesel (B10) fuel in a commercial diesel engine, International Journal of Hydrogen Energy 41: 8347-8353.
6. **Barrios, C.C.; Domínguez-Sáez, A.; Hormigo, D.** 2017. Influence of hydrogen addition on combustion characteristics and particle number and size distribution emissions of a TDI diesel engine, Fuel 199: 162-168.
7. **Bhardwaj, O.P.; Lüers, B.; Holderbaum, B.; Körfer, T.; Pischinger, S.; Honkannen, M.** 2015. Utilization of HVO fuel properties in a high efficiency combustion system SAE Research Paper 20154062, Int J Automot Eng 6: 75-82.
8. **Cardera, D.; Ryskampa, R.; Bescha, M.; Thiruvengadam, A.** 2017. Emissions Control Challenges for Compression Ignition Engines, 4th International Congress of Theoretical and Applied Mechanics, Procedia IUTAM 20: 103-111.
9. CO_2 EMISSIONS FROM FUEL COMBUS. Overview. International Energy Agency Highlights. 2017 edition. [online cit.: 2018-05-07]. Available from: http://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustion2017Overview.pdf
10. **Engman, A.; Hartikka, T.; Honkanen, M.; Kiiski, U.; Kuronen, M.; Lehto, K.; et al.** 2016. Neste Renewable Diesel Handbook. Espoo: Neste Proprietary Publication; 2016.
11. **Erkkila, K.; Nylund, N.O.; Hulkkone, T.; Tilli, A.; Mikkonen, S.; Saikkonen, P.; Makinen, R.; Amberia, A.** 2011. Emission performance of paraffinic HVO diesel fuel in heavy duty vehicles. SAE paper 2011-01-1966; 2011.
12. **Ewphun, P.-P.; Tan Vo, Ch.; Srichai, P.; Charoenphonphanich, Ch.; Sato, S.; Kosaka, H.** 2017. Combustion characteristics of hydrotreated vegetable oil – diesel blend under EGR and supercharged conditions, International Journal of Automotive Technology 18(4): 643-652.
13. **Ghojel, J.I.** 2010. Review of the development and applications of the Wiebe function: a tribute to the contribution of Ivan Wiebe to engine research, Int. Journal Engines. Vol. 11. DOI: 10.1243/14680874JER06510.
14. **Grab-Rogalinski, K.; Szwaja, S.** 2016. The combustion properties analysis of various liquid fuels based on crude oil and renewables, IOP Conference Series: Materials Science and Engineering 148(1), 012066 doi:10.1088/1757-899X/148/1/012066.
15. **Hartikka, T.; Kuronen, M.; Kiiski, U.** 2012. Technical performance of HVO (hydrotreated vegetable oil) in diesel engines. SAE Technical Paper 2012-01-1585; p. 12. http://dx.doi.org/10.4271/2012-01-1585
16. **Heywood, J.B.** 1988. Internal Combustion Engine Fundamentals. –Co – Singapore for manufacture and export (International edition); 1988. p. 930.
17. **Hilbers, T.J.; Sprakel, L.M.J.; van den Enk, L.B.J.; Zaalberg, B.; van den Berg, H.; van der Ham, L.G.J.** 2015. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim. Chem. Eng. Technol. 38(4): 651-657.
18. **Hoekman, S.K.; Broch, A.; Robbins, C.; Ceniceros, E.; Natarajanb, M.** 2012 Review of biodiesel composition, properties, and specifications; Renewable and Sustainable Energy Reviews 16: 143-169.
19. **Imperato, M.; Tilli, A.; Sarjovaara, T.; Larmi, M.** 2011. Large-bore compression-ignition engines: high NOx reduction achieved at low load with hydro-treated vegetable oil. SAE paper 2011-01-1956; 2011.
20. **Labeckas, G.; Slavinskas, S.; Kanapkiene, I.** 2017. The individual effects of cetane number, oxygen content or fuel properties on performance efficiency, exhaust smoke and emissions of a turbocharged CRDI diesel engine – Part 2. Energy Conversion and Management 149: 442-466.

21. **Lehto, K.; Elonheimo, A.; Hakkinen, K.; Sarjovaara, T.; Larmi, M.** 2011. Emission reduction using hydrotreated vegetable oil (HVO) with miller timing and EGR in diesel combustion. SAE paper 2011-01-1955; 201.
22. **Mikkonen, S.** 2008 Second-generation renewable diesel offers advantages, Hydrocarbon Processing 87: 63-66.
23. **Murtonen, T.; Aakko-Saksa, P.; Kuronen, M.; Mikkonen, S.; Lehtoranta, K.** 2009. Emissions with heavy-duty diesel engines and vehicles using FAME, HVO and GTL fuels with and without DOC + POC aftertreatment. SAE paper 2009-01-2693; 2009.
24. **Othman, M.F.; Adama, A.; Najafic, G.; Mamata, R.** 2017. Green fuel as alternative fuel for diesel engine: A review, Renewable and Sustainable Energy Reviews 80: 694-709.
25. **Pflaum, H.; Hofmann, P.; Geringer, B.; Weissel, W.** 2010. Potential of hydrogenated vegetable oil (HVO) in a modern diesel engine. SAE paper 2010-32-0081; 2010.
26. **Pirjola, L.; Rönkkö, T.; Saukko, E.; Parviainen, H.; Malinen, A.; Alanen, J.; Saveljeff, H.** 2017. Exhaust emissions of non-road mobile machine: Real-world and laboratory studies with diesel and HVO fuels, Fuel 202: 154-164. https://doi.org/10.1016/j.fuel.2017.04.029
27. **Raslavičius, L.; Keršys, A.; Starevičius, M.; Sapragonas, J.; Bazaras, Ž.** 2014. Biofuels, sustainability and the transport sector in Lithuania, Renewable and Sustainable Energy Reviews 32: 328-346.
28. **Reitz, R.D.; Duraisamy, G.** 2015. Review of high efficiency and clean reactivity controlled compression ignition (RCCI) combustion in internal combustion engines, Progress in Energy and Combustion Science 46: 12-71. https://doi.org/10.1016/j.pecs.2014.05.003
29. **Rocha, H.M.Z.; Pereira, R.S.; Nogueira, M.F.N.; Belchior, C.R.P.; Tostes, M.E.L.** 2017. Experimental investigation of hydrogen addition in the intake air of compressed ignition engines running on biodiesel blend, International Journal of Hydrogen Energy (2016) 1 – 10.
30. **Saravanan, N.; Nagarajan, G.; Narayanasamy, S.** 2007. Experimental investigation on performance and emission characteristics of DI diesel engine with hydrogen fuel. SAE Technique Paper 2007-01-17.
31. **Senthil Kumar, M.** 2003. Use of hydrogen to enhance the performance of a vegetable oil fueled compression ignition engine, Int J Hydrogen Energy 28(10): 1143-54.
32. **Silvestrini, A.; Monni, S.; Pregernig, M.; Barbato, A.; Dallemand, F.-J.; Croci, E.; et al**. 2010. The role of cities in achieving the EU targets on biofuels for transportation: the cases of Berlin, London, Milan and Helsinki. Transp Res Part A: Policy Pract 2010; 44: 403-417.
33. **Singh Bika, A.; Franklin, L.M.; Kittelson, D.B.** 2008. Emissions effects of hydrogen as a supplemental fuel with diesel and biodiesel. SAE Pap 2008-01-0648.
34. **Singh, D.; Subramanian, K.A.; Singal, S.K.** 2015. Emissions and fuel consumption characteristics of a heavy duty diesel engine fueled with Hydro processed Renewable Diesel and Biodiesel, Applied Energy 155: 440-446.
35. **Sotelo-Boyás, R.; Trejo-Zárraga, F.; de Jesús Hernández-Loyo, F.** 2012. Hydroconversion of Triglycerides into Green Liquid Fuels. Chapter 8. Hydrogeneration edited by Iyad Karamé. IntechOpen. ISBN: 978-953-51-0785-9. DOI: 10.5772/48710, 187-216 p.
36. **Sugiyama, K.; Goto, I.; Kitano, K.; Mogi, K.; et al.** 2012. Effects of Hydrotreated Vegetable Oil (HVO) as Renewable Diesel Fuel on Combustion and Exhaust Emissions in Diesel Engine, SAE Int. J. Fuels Lubr. 5(1): 205-217, https://doi.org/10.4271/2011-01-1954
37. **Szwaja, S.; Grab-Rogalinski, K. 2009.** Hydrogen combustion in a compression ignition diesel engine, International Journal of Hydrogen Energy 34: 4413-4421.
38. U.S. Department of Commerce. National Oceanic & Atmospheric Administration. Earth System Research Laboratory. [online cit.: 2018-05-07]. Available from: www.esrl.noaa.gov/gmd/aggi/aggi.html
39. **Van de Loosdrecht J.; Botes F.G.; Ciobica I.M.; Ferreira, A.; Gibson, P.; Moodley, D.J.; Saib, A.M.; Visagie, J.L.; Weststrate, C.J. and Niemantsverdriet, J.W.** 2013. Fischer–Tropsch Synthesis: Catalysts and Chemistry. In: Jan Reedijk and Kenneth Poeppelmeier, editors. Comprehensive Inorganic Chemistry II, Vol 7. Oxford: Elsevier; 2013. p. 525-557.
40. **Yeliana, Y.; Cooney, C.; Worm, J.; Michalek, D.; Naber, J.** 2008. Wiebe function parameter determination for mass fraction burn calculation in an ethanol-gasoline fuelled SI engine, Journal of KONES Powertrain and Transport 15(3).
41. **Zhou, J.H.; Cheung, C.S.; Leung, C.W.** 2014. Combustion, performance, regulated and unregulated emissions of a diesel engine with hydrogen addition, Applied Energy 126: 1-12.

Investigation on the Reliability of Axle-Box Failure Detectors in Lithuanian Railways

O. Lunys[1], M. Gorbunov[2], S. Steišūnas[3], O. Nozhenko[4]

[1]*Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania,*
E-mail: o.lunys2010@gmail.com
[2]*Volodymyr Dahl East Ukrainian National University, pr. Central 59-a, Severodonetsk, Ukraine,*
E-mail: gorbunov0255@gmail.com
[3]*Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania,*
E-mail: stasys.steisunas@vgtu.lt
[4]*Volodymyr Dahl East Ukrainian National University, pr. Central 59-a, Severodonetsk, Ukraine,*
E-mail: nozhenko.olena@gmail.com

Abstract

Detectors (HABD) system of rolling stock used in Lithuanian Railways has been assessed and its layout in the railway network has been evaluated. Theoretical and experimental studies of the determination of the temperature of the axle boxes of the rolling stock were performed. The variation of the temperature of the axle boxes of the rolling stock in the real conditions was investigated. Estimation of the accuracy of the HABD devices is based on the obtained research data. Final conclusions and improvement of the algorithm of the axle boxes heating detection of the HABD are given.
KEY WORDS: *hot axle-box detector; rolling friction; heat exchange process; axle bearings*

1. Introduction

During structural designing of new rolling stock constructions, especially with the increased lift capacity, one should pay The temperature of rolling-stock axle box housing is one of the most important diagnostic parameters, which indicates that the axle box is technically unsound. Normal operation of axle box is characterized by a constant heat exchange between its elements, wheelset and ambient temperature, i.e. when the heat output is equal to the amount of heat dissipated by the axle box and the wheelset in the environment [1, 5-7]. The temperature of the axle journal in steady mode depends on the train speed, ambient temperature, axial load and other factors. In the event of the damage to the axle box repair or assembly technology requirements, or in the event of failures during the operation of the wagons, there may be cases when unallowable heating of the axle box occurs and a wheelset journal can break after a certain period of time. The breakage of the wheelset journal due to the unallowable hot axle-box is shown in Fig. 1.

Fig. 1 View of the breakage of the wheelset axle journal

It is very important to analyse the design features of the axle box, their working capacity modes, and the characteristics that characterize the condition of the axle box under the various conditions of the train running under different loads.

The temperature of rolling-stock axle box housing is one of the most important diagnostic parameters, which indicates that the axle box is technically unsound. Normal operation of axle box is characterized by a constant heat exchange between its elements, wheelset and ambient temperature, i.e. when the heat output is equal to the amount of heat dissipated by the axle box and the wheelset in the environment [4].

The temperature of the axle journal in steady mode depends on the train speed, ambient temperature, axial load and other factors. In the event of the damage to the axle box repair or assembly technology requirements, or in the event of failures during the operation of the wagons, there may be cases when unallowable hot axle box occurs and a wheelset journal can break after a certain period of time.

The articles [2] present the investigation of the temperature of the rolling stock axle boxes in real conditions, the comparison of the heat exchange processes of the cartridge bearings and cylindrical bearings, and the investigation of

influence of the track curves on the heat exchange process.

The scientific article [5] states the distribution of temperature in the axle box node and wheelset elements. The tests were performed by simulating the speed of the rolling stock at 60 km/h by artificially blowing over the axle box unit with wind flow and artificially heating the axle box unit with a 100°C heating element. The tests lasted 25 minutes, which corresponds to 25 km of running at 60 km/h.

The breakage of axle journal can occur after 25 minutes (or if the train runs at an average of 60 km/h by 25 km) from the moment the inner bearing ring turns round the axle journal (Mironov, 2009); therefore, it is very important to arrange the HABD stations at an appropriate distance. When the inner bearing ring turns round on the axle journal (one of the most dangerous axle box failures), the temperature rises from 8ºC/min to 38ºC/min. Thus, after 25 minutes (or if the train runs at an average of 60 km/h by 25 km), the temperature of the wheelset axle journal at the point where the ring moves, can range from 266ºC to 800ºC.

The scientific article [6] presents the investigation of the changes in the velocities of hot axle box when the inner bearing ring turns round on the axle journal. The author determined by tests that as soon as inner ring turns round on the axle journal, the heating rate of axle box is 4°C/min.

2. Methods for Determination of Axle Box Failures

Hot rolling stock axle box is determined by two main ways: during wagon maintenance and HABD.

The workers performing maintenance determine the axle box fault by two main ways: visually, according to the characteristic signs of the axle box failure (change in the color of the axle box housing, shifting of the axle box housing in respect of the labyrinth ring, when the snow is melted on one of the axles of the wagon, etc.) and by touching the upper part of the axle box housing by hand (the hot one is determined by comparing the temperature of other axles of the wagon). In cases where the axle box is suspected to be defective (according to the temperature), the axle box node is first checked by means of external inspection, after which the inspection cover for determining the condition of attachment of the front bearing and the rear bearing is opened.

The second way of detecting unallowable hot the axle box during the train run is by means of trackside HABD. The main purpose of the HABD is to register unallowable hot axle boxes of the rolling stock, jammed wheelsets and rolling surface defects of the wheels, to ensure the safety of train traffic as well as detect hot axle boxes on time. The hot axle measuring devices are installed on a special hollow sleeper and the braked wheels - in the chamber for attaching the rail base.

The principle of the operation of hot axle box system is based on the measurement of the infrared radiation intensity from the control surfaces when the wheelset is moving through the measuring zones.

The HABD stations are arranged so that the distance between the control posts would be 25-35 km [2].

This system measures the absolute temperature on both sides of the axle box and within the area of wheelset axle journal (left and right, in the direction of travel) separately (Fig. 2).

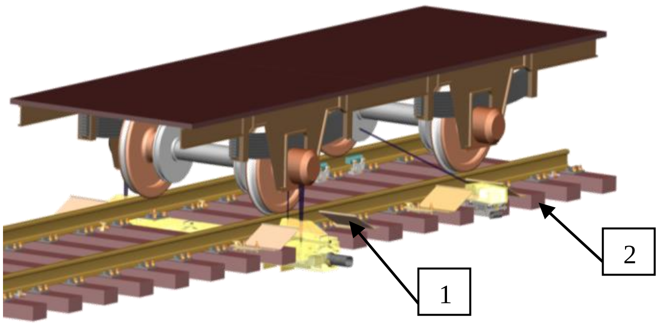


Fig. 2 The diagram of measurement of hot axle boxes, axle journals and the brake discs: *1* - radius measuring hot axle box and axle journals; *2* - the radius measuring hot braking discs

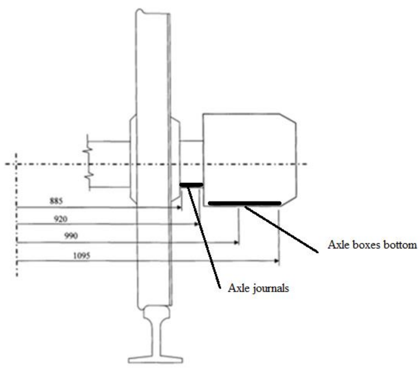


Fig. 3 A diagram of HABD measurement points of the heating of axle boxes and axle journals

A diagram of TACE measurement points of the heating of axle boxes and axle journals is given in Fig. 3.

The TACE has 3 alert levels: “Alert 0”, “Alert 1” and “Alert 2”.

3. Reasoning of Arrangement of AB “Lietuvos geležinkeliai” HABD

The diagram of the arrangement of AB “Lietuvos geležinkeliai” TACE stations (AB “Lietuvos geležinkeliai” 2008) is shown in Fig. 4, where we can see that all TACE stations are arranged on all railway lines.

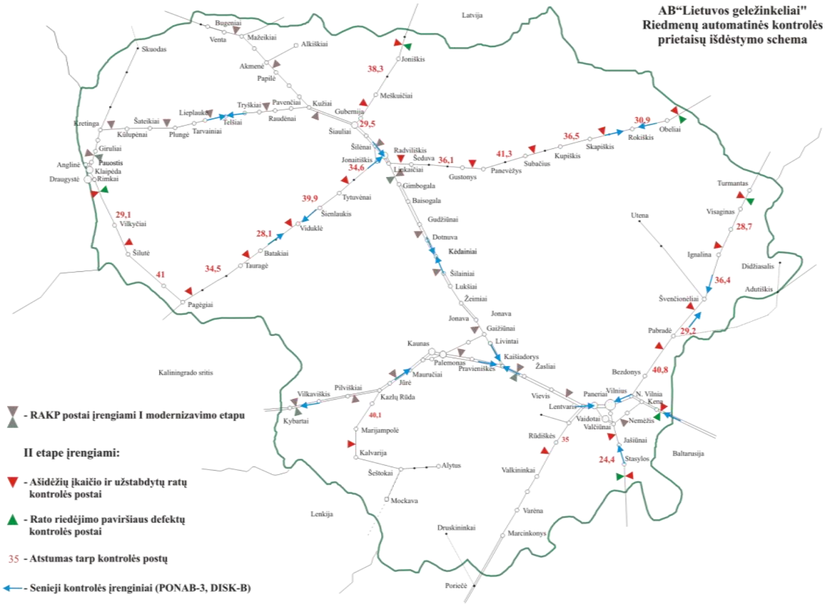


Fig. 4 The diagram of the arrangement of AB “Lietuvos geležinkeliai” HABD stations

AB “Lietuvos geležinkeliai” currently has 42 HABD stations, including:

- on the track Kaišiadorys-Radviliškis-Klaipėda - 22;
- on the track Kena-Kybartai - 7;
- on the track Kužiai-Bugeniai - 2;
- on the track Šiauliai-Joniškis-State border and Klaipėda-Pagėgiai-4;
- on the tracks Kazlų Rūda-Mockava, Lentvaris-Marcinkonys, Vilnius-Stasylos-State border, Kena-State border - 5;
- on the track Radviliškis-Pagėgiai-State border - 4;
- on the track Radviliškis-Obeliai-State border - 5;
- on the track N.Vilnia-Turmantas - 4.

After analysing the arrangement of AB “Lietuvos geležinkeliai” TACE stations, it was found that the distances between the HABD stations range from 13.6 km to 41.4 km.

The minimum distance between HABD is on the track section Kaišiadorys-Radviliškis-Klaipėda, which are between the Gimbogala-Radviliškis and Radviliškis-Šilėnai plain tracks and make 13.6 km, while the maximum distance is on the track section Radviliškis-Obeliai-State border between HABD stations of Gustoniai-Panevėžys and Subačius-Kupiškis and makes 41.4 km.

4. Research Methods and Results

Temperature change of the rolling stock axle-boxes when the train is moving was investigated according to the readings of the hot axle-box detection devices (temperature values) at HABD.

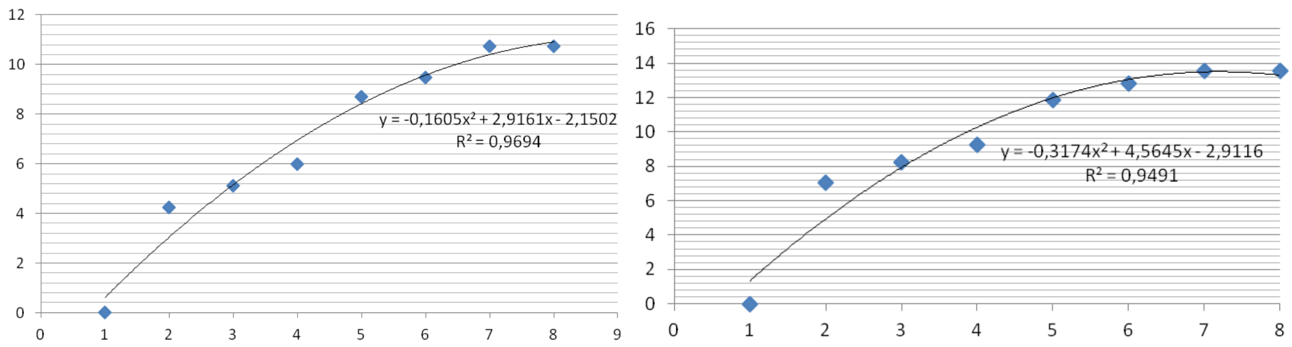
Firstly, it was investigated how the axle box temperatures of the rolling stock vary throughout the entire train travel route from the initial to the terminal. During the travel, the axle box temperature changes according to the exponent and is a random size that depends on many factors: ambient temperature, train speed, etc. Each axle box heat exchanger process takes place in its own way. The investigation found that the axle boxes reach the operating heat after having run about 50 km from the initial station (at an average train speed of 60 km/h).

The criteria for the smallest squares were applied to the obtained results and the distribution diagrams were drawn up (see Fig. 5). Fig. 5 shows that the determination coefficient of freight wagons is 0.9694, and the freight locomotive 2M62M is 0.9491.

The figure shows that the greatest change in the temperature of the axle boxes occurs when the train leaves the initial station to the first TACE station (distance 28.2 km). This phenomenon can be explained by the fact that trains are formed in the initial station within a certain time, during which the physical properties of the axle box unit can change (e.g. viscosity of the lubricant). In the rolling stock axle box, which has been idle for some time, there is a significantly

higher friction between the moving parts (e.g. between the roller and the lubricant) during the initial running stage resulting in a significantly higher heating rate. After estimating this fact, it can be stated that uniform heat exchanger process of each axle box takes place “in own time”.

The maximum temperature variation rate of the axle box is from the initial station to first TACE station - 0.15 °C/min. (distance 28.2 km), and the temperature variation rate of the axle box decreases to 0,03 °C/min. from the first TACE station to the second TACE station (29.8 km). The same phenomenon is also observed in the axle boxes of the 2M62M freight locomotive: the maximum temperature variation rate of the axle box from the initial station to the first TACE station and makes 0.25°C/min, then the change rate decreases to 0.06°C/min. This leads to the conclusions that on average, the uniform heat exchange process in axle boxes between the axle box unit and the wheelset components starts when the train has travelled about 50-60 km from the initial station.



a b

Fig. 5 Distribution diagram of rolling stock axle box temperatures: a - freight wagon; b - freight locomotive2M62M

After conducting the natural tests, the following operating change rates of the axle box temperatures were determined:

- Locomotive (2M62M) – 0.07 ÷ 0.25 ºC/min;
- Loaded freight wagon – 0.03 ÷ 0.15 ºC/min;
- Empty freight wagon – 0.016 ÷ 0.15 ºC/min;
- Passenger wagon – 0.014 ÷ 0.15 ºC/min.

The average operating heating rates are the basis for compiling the prognosis algorithm of residual resource of the axle boxes to the marginal heating.

It was explored by State Company “Lietuvos geležinkeliai“ (Lithuanian Railways) how many trains were halted in 2013 due to impermissibly hot axle boxes. The obtained results are presented in Fig. 6.

In 2013, 259 trains were halted according to HABD, of which: 245 freight trains and 14 passenger trains. Figure 6 shows that in January, the recorded amount of hot axle boxes is almost by 70% bigger than in February. This phenomenon is explained by the fact that at the end of December 2012, the railways started the operation of the wagons equipped with cartridge-type bearings, whose heat exchange processes differ considerably from axle boxes equipped with standard type bearings. In order to avoid unsound halt of trains, a threshold alert temperature has been increased in the TACE.

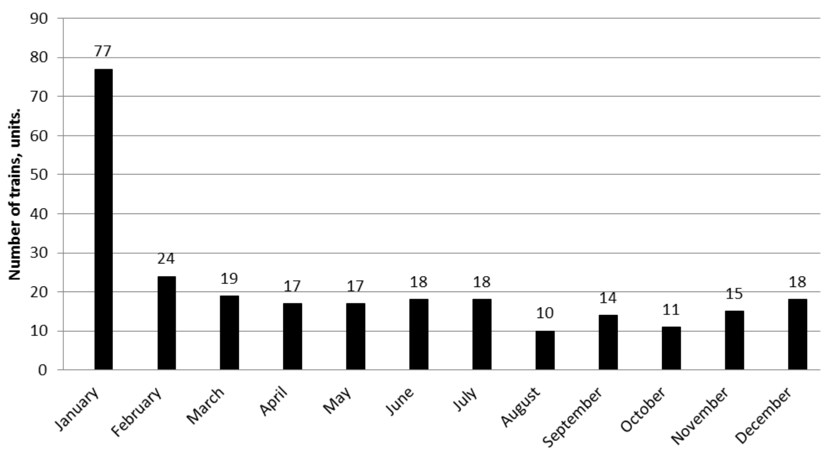


Fig. 6 Dynamics of HABD halted trains with impermissibly hot rolling stock axle-boxes

The investigation revealed that up to 55% of unallowable hot axle boxes are recorded by the first and second HABD on train travel route.

The number of the trains halted by alert levels is shown in Fig. 7.

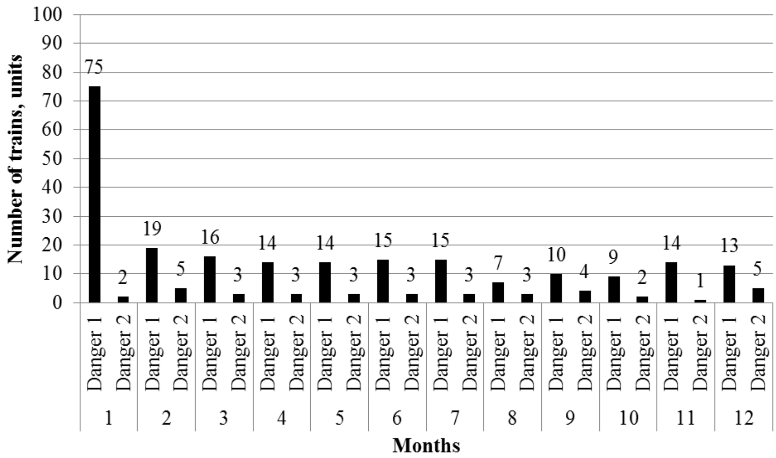


Fig. 7 Dynamics of trains halted in 2013 by danger levels

37 freight trains were halted by Alert Level 2 in 2013, of which 37 freight wagons with unallowable hot axle boxes were uncoupled.

After demounting of 37 axle boxes for precise failure detection, the following faults were detected:

a) water in the lubricant – (14 axle boxes);
b) metal chips in the labyrinth part – (4 axle boxes);
c) cuts and burrs in the labyrinth part of the body – (13 axle boxes);
d) scratches in a herringbone pattern at the bearing roller ends – (1 axle box);
e) loose fixing screws M20 – (1 axle box);
f) crack of the inner ring of the front bearing – (2 axle boxes);
g) too excessive lubricant – (2 axle boxes).

Additional examination of temperature variation rate of these axle boxes shows that not only the failure of axle box itself, but also the nature of the failure can be predicted.

The investigation found that unallowable hot axle boxes on 123 freight wagons out of 245 freight trains were detected in the first and second TACE stations, where the distance from the initial station was between 50 km and 60 km. Following the examination by train drivers, all 123 trains continued their planned travel, while other TACEs on the train travel route did not register any hot axle boxes anymore. In this regard, it can be concluded that the heating of the axle boxes of these wagons has not been confirmed.

The investigation revealed that the temperature variation rate of axle boxes of freight wagons in all 123 freight trains was up to 0.15ºC/min. (which corresponds to the operating change rate in temperature of axle boxes for this type of rolling stock determined by authors’ research).

The total downtime of 245 freight trains resulting from halt due to TACE readings was 247.28 hours, while 14 passenger trains - 1.17 hours.

The average duration of the downtime of one train is calculated according to the following formula:

$$t_{tr.} = \frac{\sum nt_{tr.}}{\sum n}, \tag{1}$$

where $\sum nt_{tr.}$ - duration of the downtime of the train at the stations in hours; $\sum n$ - number of trains.

The losses incurred due to halted trains by the TACE readings can be calculated according to the following formula:

$$Y = \sum nt_{tr.} \times K, \tag{2}$$

where K – train price per hour, EUR.

In 2013, AB “Lietuvos geležinkeliai” incurred the loss of EUR 102.49 thousand resulting from halt of the freight trains by HABD (without the costs of other delayed trains, train halt and acceleration, as well as additional examination of halted trains by wagon economy workers).

If the HABD had been equipped with the prognosis algorithm of residual resource to the marginal heating and the operating temperature variation rate of the axis boxes determined in this paper, the losses of AB “Lietuvos geležinkeliai” would have been less by about EUR 50 thousand or about by 52%.

The economic evaluation of the work could lead to the statement that following the installation of tracking of trends of hot axle boxes in the HABD algorithm throughout the railway line, where the train travels, the economic effect can amount to about 50% of halted trains, where the heating has not been confirmed.

5. Conclusions

The distance even among 11 LG TACE stations out of 42 TACE stations is greater than recommended 35 km.

During the train travel, the temperatures of axle boxes increase by the exponent.

The temperatures of hot axle boxes are influenced by train travelling modes.

Axle box failures can be predicted according to the temperature variation rate.

The operating temperature of the axle boxes is reached after running a distance of 50-60 km from the initial station.

The following operating temperature variation rates of axle boxes were determined:

- Locomotive (2M62M) – 0.07 ÷ 0.25 ºC/min;
- Loaded freight wagon – 0.03 ÷ 0.15 ºC/min;
- Empty freight wagon – 0.016 ÷ 0.15 ºC/min;
- Passenger wagon – 0.014 ÷ 0.15 ºC/min.

The operating temperature variation rates of the axle boxes allow to predict the temperature of the axle boxes for any TACE located ahead.

In 2013, AB “Lietuvos geležinkeliai” incurred the loss of EUR 102.49 thousand resulting from halt of the freight trains by HABD.

With the implementation of the prognosis algorithm of residual resource to the marginal heating on the HABD, the economic effect may be about 50% of the halted trains where the heating has not been confirmed.

Acknowledgement

This research was funded by a grant (No. S-LU-18-12) from the Research Council of Lithuania. This research was performed in cooperation with the *Volodymyr Dahl East Ukrainian National University, Ukraine.*

References

1. **Hoeprich, M.R.** 1996. Rolling-element bearing internal temperatures, Tribol. Trans. 39(4): 855-858.
2. **Lunys, O.; Subačius, R.** 2012. Riedmenų ašidėžių kaitimo temperatūrų kitimo tendencijos [Analysis of tendencies towards changes in temperatures of railway vehicle axle-boxes]. Mokslas-Lietuvos ateitis: Statyba, transportas, aviacinės technologijos 4(4): 361-365.
3. **Wang, S.; Cusanom C.; Conrym T.F.** 1993. Dynamic model of the torque and heat generation rate in tapered roller bearings under excessive sliding conditions, Tribol. Trans. 36(4): 513-552.
4. **Довбня, Н.П.; Бондаренко, Л.М.; Коренюк, Р.А.** 2009. О величине работы на нагрев подшипников букс локомотивов и вагонов [The magnitude of the heating bearing axle boxes of locomotives and wagons]. **–** Проблемы трибологii 3: 16-17.
5. **Миронов, А.А.** 2008. Виртуальная модель бесконтактного теплового контроля буксовых узлов подвижного состава [Virtual model of the contactless thermal control axle-boxes units of a rolling stock].**–**Транспорт Урала 3(18): 59-65.
6. **Миронов, А.А.** 2009. Имитационная модель функционирования аппаратуры теплового контроля буксовых узлов подвижного состава [The imitating model of functioning of the equipment the thermal control of axle-boxes].**–**Транспорт, наука, техника, управление 5: 8-14.
7. **Миронов, А.А.; Образцов, В.Л.; Митюшев, В.С.; Салтыков, Д.Н.** 2008. Тепловой контроль буксовых узлов инфракрасной оптикой [Thermal control axle-box units infrared optics]. **–** Локомотив 4: 29-32.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Analysis of Safety of Flights of Airbus A320

S. Hoskova-Mayerova[1], M. Woch[2], P. Krzysiak[3], J. Tomaszewska[4], M. Zieja[5], J.Żurek[6]

[1]*University of Defence, Faculty of Military Technology, Kouicova 65, 66210 Brno, Czech Republic, E-mail: sarka.mayerova@unob.cz*
[2]*Warsaw University of Technology, Division of Fundamentals of Machine Design, Faculty of Power and Aeronautical Engineering, 00-665 Warsaw, Poland, E-mail: marta.woch@itwl.pl*
[3]*Faculty of Aviation. Polish Air Force Academy, ul Dywizjonu 303, 08-521 Dęblin, Poland. E-mail: p.krzysiak@wp.pl*
[4]*Faculty of Aviation. Polish Air Force Academy, ul Dywizjonu 303, 08-521 Dęblin, Poland. E-mail: j.tomaszewska@wsosp.pl*
[5]*Air Force Institute of Technology, Division for IT Support of Logistics, 01-494 Warsaw, Poland, E-mail: mariusz.zieja@itwl.pl*
[6]*Faculty of Aviation. Polish Air Force Academy, ul Dywizjonu 303, 08-521 Dęblin, Poland. E-mail: j.zurek@wsosp.pl*

Abstract

Taking care about the safety of the passengers is the most important issues for any kind of transport. The aim of this article is based on the available data from the years 1988-2018 the statistical assessment of accidents of aircraft Airbus A320. In order to analyze the dependences of occurrences and factors taking place during Airbus A320 accidents, the database published on www.aviation-safety.net was employed. There are included the date and the location of the accident, the number of casualties, name of the air carrier and above all, a short description of the accidents circumstances and its cause. The data (qualitative and quantitative) were grouped with respect to flight stages, the time of accident and continents. In spite of the fact that the number of accidents in the stage of landing is the most significant, it does not find the reflection in the number of deaths. The objective of the analysis was, above all, drawing a reader's attention to the distribution of accident frequency in various circumstances. Despite the fact that Airbus A320 is relatively small aircraft, the statistical analysis regarding it, is the source of valuable information which are the base for investigating the problem in general and draw practical conclusions.
KEY WORDS: *Airbus A320, accident, statistical distribution, fatalities*

1. Introduction

In the resent years the number of the passenger traffic has been increased and it consequent in the number of executed aircraft operations. This trend is the result of the open market as well as the access of the middle income countries to the aviaton market. Aircraft manufacturers and design engineers are necessitated to introduce the most recent technologies, which will not only improve the safety of flights performed, but also the aircraft steering. New applications (fly-by-wire, onboard systems) [9] have been implemented mainly to minimize or eliminate, in some case, aircraft accidents. The paper come out -uses the data collected by Krzysiak under the supervision of Tomaszewska for the conference [4].

2. Methodology

In order to analyze the correlation of occurrences and factors taking place during Airbus A320 [6, 8] accidents, the database published on www.aviation-safety.net was employed. [10] The choice of the portal was enforced mainly by its credibility and accuracy of gathered data since it is produced by the Australian group Flight Safety Foundation, which is an international non-profit organization exclusively chartered to provide impartial, independent, expert safety guidance and resources for the aviation and aerospace industry. The Foundation is in a unique position to identify global safety issues, set priorities and serve as a catalyst to address these concerns through data collection and information sharing, education, advocacy and communications. The Foundation's effectiveness in bridging proprietary, cultural and political differences in the common cause of safety has earned worldwide respect. The common good of safer air travel continues to inspire individuals and organizations to rise above competitive interests towards shared objectives. Since Flight Safety Foundation was organized in 1947 by Jerome F. "Jerry" Lederer, it has initiated projects and developed products to reduce risk and improve aviation safety worldwide. Today, membership includes more than 1,000 organizations and individuals in 150 countries. The Foundation is based in Alexandria, Virginia, U.S., has a regional office in Melbourne, Australia [10].

The database of A320 published on the above-mentioned site includes the date and the location of the accident, the number of casualties, name of the air carrier and above all, a short description of the accidents circumstances and its cause (backed up by the official reports of the investigation commission). The data (qualitative and quantitative) were grouped with respect to flight stages, the time of accident and continents.

The outcome of the dependences is the data graph display which makes the statistical analysis possible. Descriptive statistics was chosen for the analysis as the most relevant method.

Descriptive statistics are used to describe the basic features of the data in a study. They provide simple summaries about the sample and the measures. Together with simple graphics analysis, they form the basis of virtually every quantitative analysis of data.

All descriptive statistics (the mean, median, mode, standard deviation, kurtosis or skewness) are either measures of central tendency or measures of variability. These two measures help to understand the meaning of the data being analyzed. Measures of central tendency describe the center position of a distribution for a data set. A person analyzes the frequency of each data point in the distribution and describes it using the mean, median or mode, which measure the most common patterns of the data set being analyzed.

Measures of variability, or the measures of spread, aid in analyzing how spread-out the distribution is for a set of data.

Lets have a file with *n* values $X = \{x_1, x_2, \dots, x_n\}$ and their weights $W = \{w_1, w_2, \dots, w_n\}$. The *mean* is found by adding up all of the given data and dividing by the number of data entries, thus it can be calculated as follows:

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n}.$$

The *weighted average* is given by the formula:

$$x = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}.$$

The *median* is the "middle" value in the list of numbers. To find the median, numbers have to be listed in numerical order from smallest to largest. This allows to analyze the data in many various ways. Moreover, also numerical values chart was inserted to emphasize some numerical data.

Statistical data enable close examination of the facts linked with the incidents with A320 involvement and their analysis allows to draw conclusions thanks to which the regularity of ensuing situations can be formulated.

3. Results

In the resent years the number of the passenger traffic has been increased and it consequent in the number of executed aircraft operations. This may be result in an increase in the number of accidents per year. The numer of accidents per year is presented in Table 1.

Accidents occur in all flight stages, however the likelihood of the incident is the greatest in the final stage of landing approach as well as take-off. [6,10] Both maneuvers are the most difficult and the most encumbering operations for pilots, requiring making rapid decision in the situation of potential imperilment. The theory is also confirmed in the case of A320 (Fig): 46% of accidents happened in the landing phase. The following position is held, in this respect, by cruising level (17%). The stage of standing accounts for a large number (14%). In this stage, sabotage actions damaging the aircraft and fires during refueling took place. Taxing and ascending (3% each) have constituted one of the safest stages of flight so far. 2% of the incidents were not qualified to any of the standard stages of flight due to insufficient data.

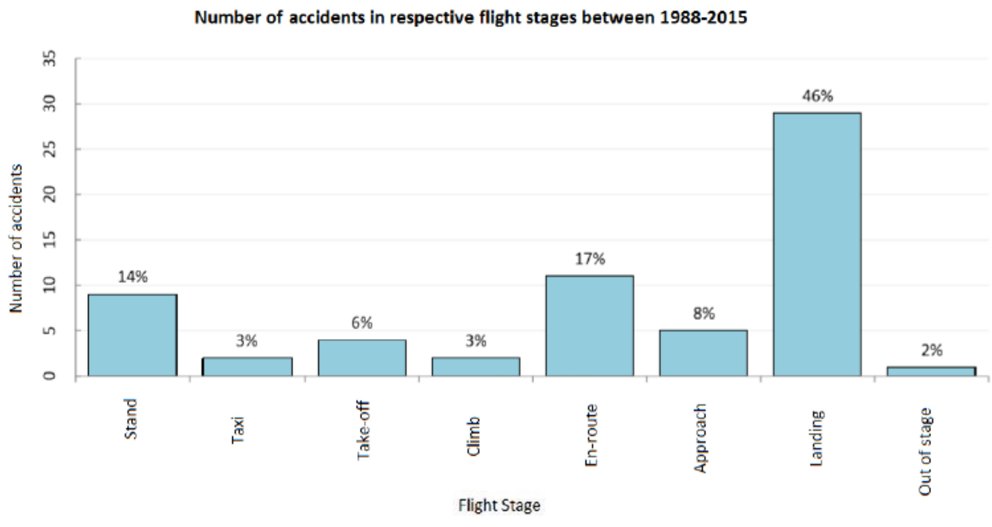


Fig. 1 Relation of number of accidents to respective flight stages of A320

In opposite the landing stage is considerably safe stage for A320 (the quotient of deaths to the number of accidents equals 7.2, which indicates that each accident during the landing stage resulted in approximately 7 casualties), when the number of deaths is taken into consideration.

422 people lost their lives during the approach, where the number of accidents constitutes 5 cases. The quotient in this issue equals 88.4, which accounts for 88 casualties in one accident in this stage of the flight. Such value brings the conclusion that, in respect of statistics, more people die during approach than landing. Therefore, in the case of Airbus A320, the greatest likelihood of casualties is related to this particular stage of approach.

The data collation makes it possible to examine the number of accidents in different flight stages in respective continents.

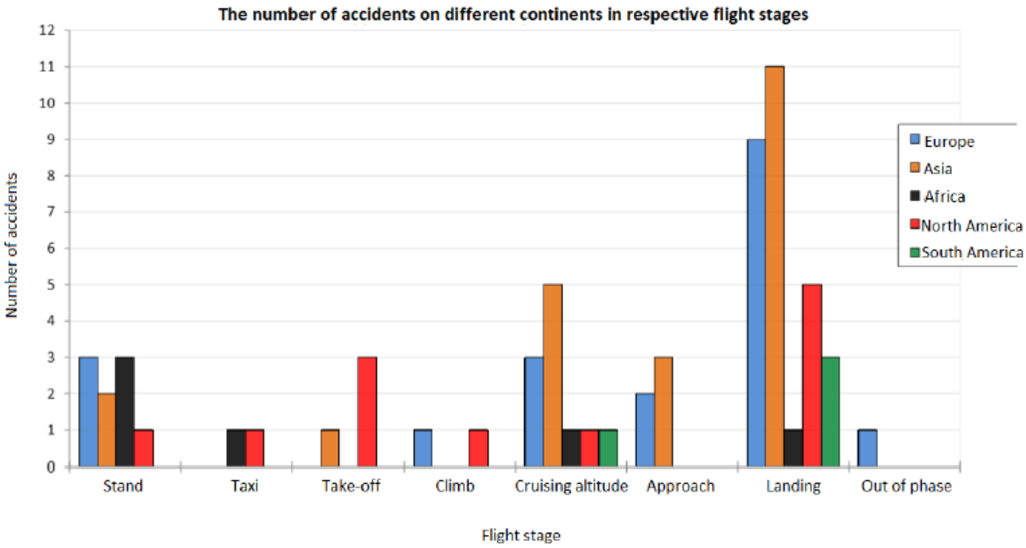


Fig. 2 Number of accidents on different continents in respective flight stages

Analysing the graph (Fig) it can be observed that the uppermost values are related to the stage of landing. It means that the greatest number of accidents with A320 involvement occurred in this particular stage. It is also conspicuous that Asia is the leader in this respect among other continents with 11 accidents during landing. The European continent is situated after Asia with 9 incidents. In the stage of cruise and approach, Asia takes on the paramount values among all continents – 5 and 3 accidents respectively. South America is the only continent where the accidents happened exclusively during landing and cruising. Relatively quite a number of incidents occurred during the aircraft parking. As mentioned above, it is linked with sabotage actions, mainly in Africa, aircraft fires or aircraft damages caused by ground personnel. The greatest number of accidents during take-off is assigned to North America, however, none of the people present on board lost their lives in any of them.

Such distribution (especially in terms of landing) may back up the thesis formulated beforehand, which mentions, among others, high difficulty level of piloting in the final stage of approach and landing itself. As far as cruising is concerned, each continent experienced at least one incident in the present flight stage. Collating these values with the number of casualties (Table 1), it can be deducted that this part of flight is quite dangerous despite not implementing direct danger of contact with the terrain. The total numbers of accidents and casualities for all continents have been summarising in the Table 1.

Table 1

Total numbers of accidents and casualities for all continents

Continent	Numer of accidents	Numer of casualities	Numer of aircraft in operation
Europe	26	249	1080
Asia	24	514	1703
Africa	7	66	93
North America	12	0	524
South America	4	204	342

4. The Frequency of Accidents in Respective to Months

The available data allows to pay attention to the months with the greatest and smallest accident frequency. In this term, March is on the lead (16%) while both September and November are the months with the smallest number of accidents (3%) when Airbus A320 is in operation. The incident occurrence median in respective months takes the value of 5, which indicates the month of May and the mean average is 5.8 (Fig. 3).

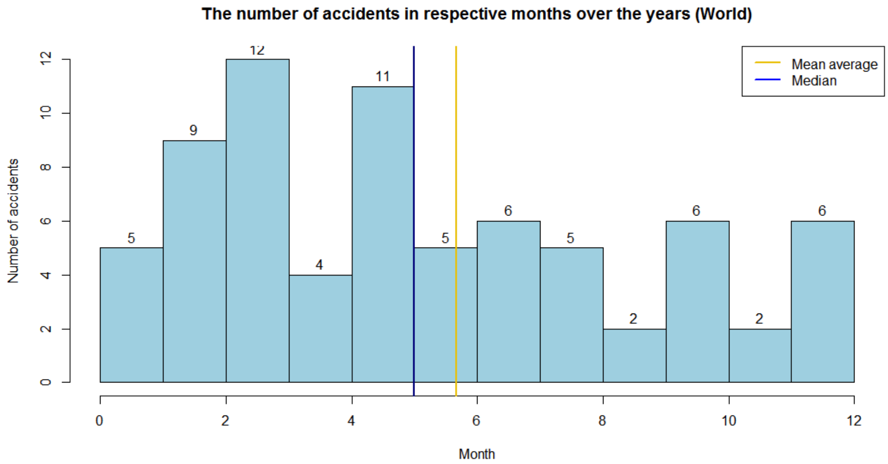


Fig. 3 The number of accidence in respective months over the years (World)

Such distribution of accidents may have the direct correlation with unfavorable atmospheric conditions occurring in early-spring months in the north hemisphere. It is the time when the human organism is more prone to more rapid tiredness, limited concentration and bad moods. Moreover, at that time, visibility is reduced, relatively strong winds blow and the average precipitation is increased. Considering the fact that 84% accidents involving A320 took place in the north hemisphere, the weather factor can play a significant role in shaping statistics.

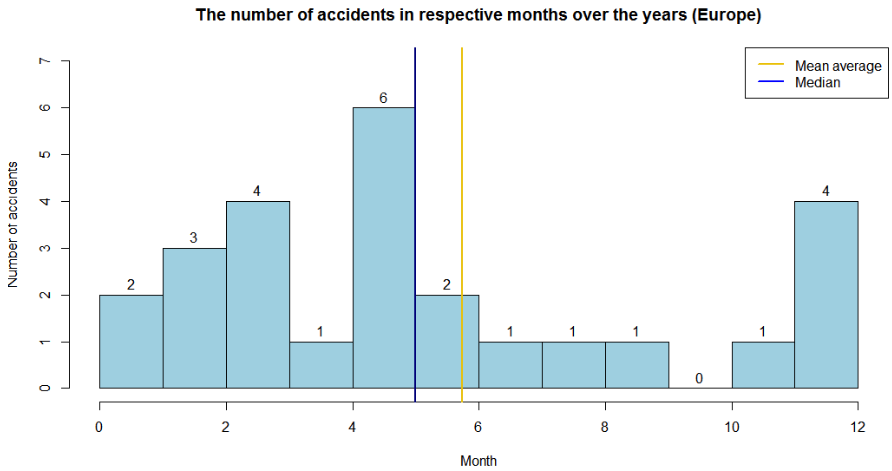


Fig. 4 The number of accidence in respective months over the years (Europe)

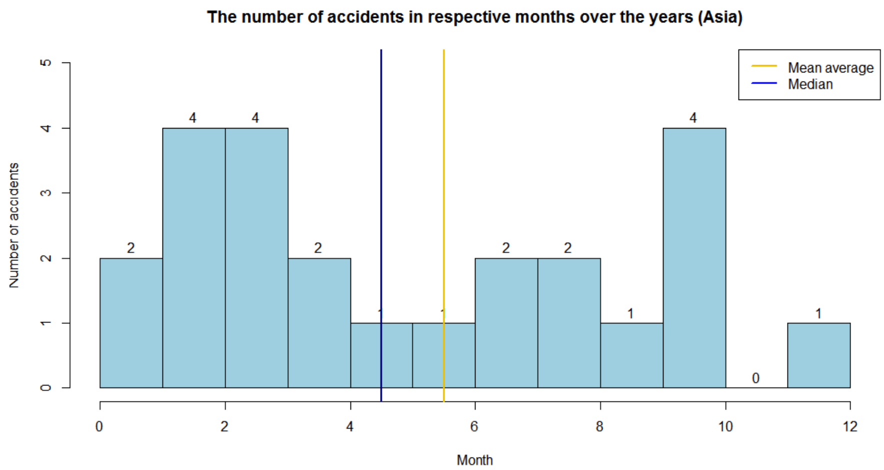


Fig. 5 The number of accidence in respective months over the years (Asia)

In order to explain the shape of Fig and Fig it will be necessary to involve specialists from another branches, as it is necessary to take into consideration not only weather conditions but also cultural habits, economic situation in

different part of the world, level of education and many others items. [2, 3, 5].

5. The Number of Aircraft in Operation and the Age of the Airplane at the Time of the Accident

In order to examine if the airplane's age translates into the number of accidents, it is necessary first to determine its time of life at the moment of the accident on the particular continent, and average the results afterwards. The results of the analysis are presented in the following graph. The values above the bars indicate the average aircraft age expressed in years.

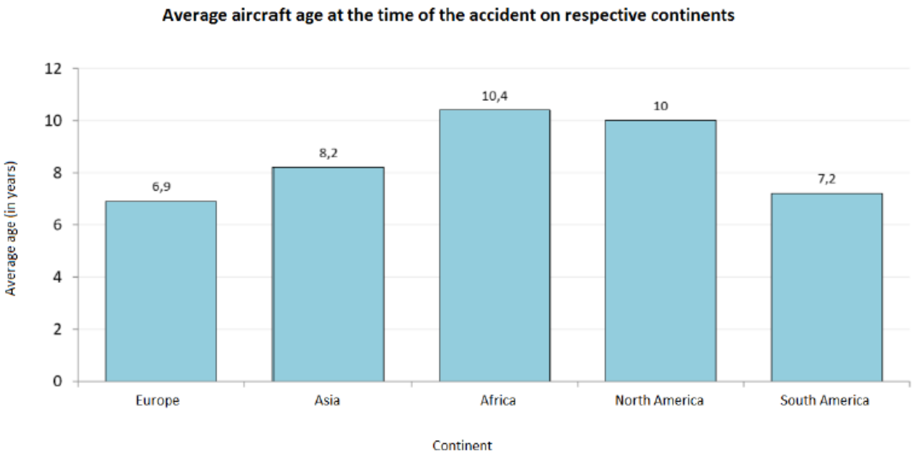


Fig. 6 Average aircraft A320 age at the moment of accident

The analysis of the chart allows to draw the conclusion that older airplanes participate in incidents in Africa more often than on other continents. African countries, which are economically underdeveloped, purchase the aircraft from wealthier countries which replace the fleet after some period of exploitation. Frequently, they are faulty in a way and require an overhaul. Negligence of the ground personnel results in some defects which consequently may translate directly into the flight safety. The Africa aircraft average age of 10.4 years seems to prove the theory, which applies not only to Airbus A320 accidents (Fig. 6).

The continent possessing the newest aircraft is Europe with the result of around 7 years of age. Similar value applies to South America, however the number of aircraft in operation is considerably smaller than in Europe. The average age for all continents amounts to around 8.5 years.

One of the variables, the age of the aircraft, does not indicate precisely the correlation and link between the number of accidents and number of casualties. In order to check the correlation and hypothesis, which claims that accidents occur more often among the older aircraft than newer one, the analysis of several variables has to be conducted, see also [7,8]. Another interesting approach can be found e.g. in [1].

6. Concusions

The escalation of accidents is lowered by means of reliable solutions. Over the years, technologies have been improved and modernized in order to enhance safety in aviation. However, these actions have not eliminated the problem of accidents completely. The example can be one of the most popular narrow-body aircraft – Airbus A320, whose innovative technologies improved flight safety only in some cases.

Due to the conducted research and analysis it is possible to look into the issue of A320 safety. The data collation enabled to formulate regularities and draw conclusions.

In spite of the fact that the number of accidents in the stage of landing is the most significant, it does not find the reflection in the number of deaths. In the case of A320, it is inappropriate to claim that: "landing is the most dangerous stage of the flight" because the statement is in imprecise. Similar correlation applies to the aircraft age – the widespread opinion, especially among the elderly, that older aircraft are more prone to accidents than newer one, is also mistaken. The Asian continent prevails in the number of accidents, however, if the number of aircraft in operation is taken into account, it appears that Asia, in fact, comes second after South America in respect of the smallest percentage of accidents (1.29%). The largest percentage (6.45%) is linked to Africa. What is also worth attention, is the number of accidents in relation to month of the year – their frequency is the uppermost in the first quarter. Such distribution may not only be the outcome of prevailing atmospheric conditions but human factor as well.

The objective of the analysis was, above all, drawing a reader's attention to the distribution of accident frequency in various circumstances. Considering the fact that Airbus A320 is relatively small aircraft, the statistical analysis regarding it, is the source of valuable information which are the base for investigating the problem in general and draw practical conclusions.

Funding Statement

The work presented in this paper was supported within the project [Project code: MOBAUT] by the Ministry of Defence of the Czech Republic and also was supported by MŠMT ČR, research project no. [*SV17-FVL_K106-BEN*]: "Identification and security of places with high population movement".

References

1. **Bořil, J.; Čičmanec, L.** 2016, Tactical Mission Execution on Flight Simulators with Evaluation of Measurement Data. In: Transport Means 2016. Juodkrante, Lithuania: Kaunas University of Technology, 264-267.
2. **Hruby, M.; Hasilova K.** 2018. Education of human resources for contemporary technical society. In: Proceedings of the 15th International Conference Efficiency and Responsibility in Education 2018. Prague: Czech University of Life Sciences Prague, 103-109.
3. **M. Keller, M.; Fredrickson, O.; Ybarra. A.** 2005. Warm Heart and a Clear Head. The Contingent Effects of Weather on Mood and Cognition, Psychological Science, 2005, p. 725.
4. **Krzysiak, P.** 2016. AIRBUS A320 Accident Analysis, CEFME Students' Scientific Conference 2016 University of Defence, Brno.Presented under the supervision of Justyna Tomaszewska PhD.
5. **Maturo, F.; Hoskova-Mayerova, S**. 2017. Fuzzy regression models and alternative operations for economic and social sciences, Studies in Systems, Decision and Control 66, 235-247, DOI: 10.1007/978-3-319-40585-8_21.
6. **Norris, G.; Wagner, M.** 1999. Airbus, MBI Publishing.
7. **Vališ, D.; Hasilová, K.; Žák, L.** 2017. Combustion engine condition estimation based on indirect diagnostics data. In: Risk, Reliability and Safety: Innovating Theory and Practice. London: Taylor & Francis Group, 1930‑1936.
8. **Woch, M.; Zieja, M.; Tomaszewska, J.** 2017. Analysis of the Time between Failures of Aircrafts, International Conference, 112-118.
9. **Airbus**. Fly-by-wire, [online cit.: 2018-05-22]. Available from: http://www.airbus.com/innovation/provenconcepts/in-design/fly-by-wire/
10. **Flight safety Foundation**, [online cit.: 2018-05-22]. Available from:https://flightsafety.org/foundation/ Airbus. Orders, Deliveries and Operators, October 2015.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Intercultural Differences in Automotive After Sales – Comparison of Customer Demands and Production Conditions in Germany and Mexico

C. Aigner, M. Hege, H. Lücken

Esslingen University of Applied Sciences, Kanalstr. 33, 73728 Esslingen, Germany,
Corresponding Author: hermann.luecken@hs-esslingen.de

Abstract

The German and the Mexican automotive industry differ in many ways. Especially for automotive after sales it is necessary, to take the cultural aspects of each country in consideration to be successful in distributing cars on the one hand and in manufacturing cars, components or spare parts that meet the customer requirements on the other hand.
This study analyses the situation in Germany and Mexico in two ways. Based on a previous market research two types of investigations have been carried out: interviews with experts of automotive companies with production or sales activities in both countries and an online questionnaire which was answered by Mexican and German customers. The aim of the project was to find out the differences that global or expanding companies have to consider in both markets.
The customer questionnaire as well as the expert interviews showed, that the basic requirement for successful car or car part production and sales is the sustainable achievement of cost and quality goals. However, the reasons for buying new vehicles and the requirements the product has to fulfill are quite different in both countries.
The study gives answers how to handle the operational problems that arise in this topic and gives a guideline for the strategic planning.
KEY WORDS: *automotive after sales, intercultural differences, expert interviews, online questionnaire, requirements for production and sales in Germany and Mexico*

1. Introduction

Since the automotive industry produces increasingly global there are different obstacles and differences that have to be considered when expanding into other countries and other markets. The differences range from the environmental conditions, economy, mentality up to service and more. Each country, customer, employee or company has different challenges that the manufacturers and producers have to meet. In a joint research project of Esslingen University and Tecnologico de Monterrey the situation in Germany and Mexico was analyzed. The goal of the project was a qualitative analysis of the differences that global or expanding companies have to consider when doing business in the car industry in Germany or Mexico. For the detection of the differences in this project different types of analytic methods have been used. First the market research by internet investigation and literature gives an overview. The second step was an online questionnaire to different groups in the two countries. As a third step structured interviews with experts in sales and after sales in the automotive industry have been performed.

2. Background and Market Situation

Mexico and Germany are one of the most successful car-producing countries in the world. Germany and Mexico are listed in the top ten, while Germany maintains its position longer than Mexico, that upholds its position since 2011. Germany is known for its outstanding automotive industry. This industry is the largest industry in Germany and according to the "Verband der Automobilindustrie" it raises about 20% of the whole industry income. Three quarters or 4.4 million produced cars are exported. Cars produced in Germany have a positive image worldwide. They are well known for high quality including engineering, innovation, reliability, safety and design. Germany has an automotive manufacturing tradition, causing high production standards and sustainable knowledge, but these high standards lead to high labor costs. A big segment of the automotive industry in Germany is the premium vehicles, from which the most exclusive ones get mostly exported to the Chinese market. In the premium vehicles segment Germany is even the leading producer worldwide. But not only the high quality and production rate are advantages of Germany. The German automotive engineers are looking forward to the future and work on developing and improving alternative drive technologies like electric, hybrid or fuel cell cars. One reason for the high interest in the e-mobility might be the diesel crisis, which is caused by German car manufacturers cheating diesel emission tests. This crisis is a big risk for the German automotive industry because the impact of this crisis is unpredictable, based on the statement of Finance Ministry at August 21st, 2017. As a result of this crisis the automotive manufacturers overhaul engine software of millions of diesel driven cars to decrease the emissions and to improve the damaged reputation of the German automotive industry. The German government reacts with stronger regulations for CO_2 emissions and rigorous controls [1, 2].

Mexico is a leader in manufacturing and export of light vehicles. Among the export nations in automotive

business, Mexico is in fourth place; it holds the eighth position in car production [3]. Most of the cars are produced for the USA, other potential markets are Central and South America. The increase in production capacity of the existing facilities will result in an increase of suppliers to meet the demand. According to the “asociación mexicana de la industria automotriz a.c. AMIA” (engl.: national automotive association) the export and the production of cars in 2016 are higher than the years before [4]. Mexico has good boundary conditions for the production of cars, which is the reason why many big automotive manufacturers have factories there. One of the most important reasons is that Mexico has the most free trade agreements even with the USA. Therefore, the customs duties for exported cars and automotive parts can be reduced or eliminated. The geographical location of Mexico is very good because it is close to the USA and South America. By producing in Mexico, it is easier to reach these markets and there are less transportation and export costs caused by the proximity to these countries and the free trade agreements. That gives the automotive manufacturers the opportunity to expand their existing markets or to develop new markets. But not only the basic conditions are reasons for producing in Mexico. The manufacturing car industry itself is very modern, efficient and high technologies make the processes very flexible, moreover the labor costs are low.

Producing in Mexico has also some disadvantages. One of the most important disadvantages is the high dependency on the USA, because three-quarters of the exported cars are being sold in the US market. Nowadays the high dependency on the US is especially a disadvantage, as the economic political stability is no longer the same with the actual US administration under President Donald Trump [3-5].

3. Research Question and Analysis Methods

The goal of this project is to find out the differences between Germany and Mexico in terms of the requirements for the automotive industry. Thereby, the aspects for different demands of the customers and by this different requirements for the construction of products will be examined. Since this topic is very wide, the focus will be on the differences of the production conditions, the service offers, the construction terms and the intercultural differences. The environmental and political circumstances should also be considered. The investigations have been carried out by expert interviews and an online questionnaire.

4. Results of the Online Questionnaire

The online questionnaire reveals 306 responses. It has to be mentioned that the link to the questionnaire is mainly distributed in the regions of Stuttgart and Monterrey.

A key question for the successful marketing of products is the one of the motivation of the customer to buy the product. In terms of buying a new car the most important considerations are evaluated in percentage of the respondents of the particular group.

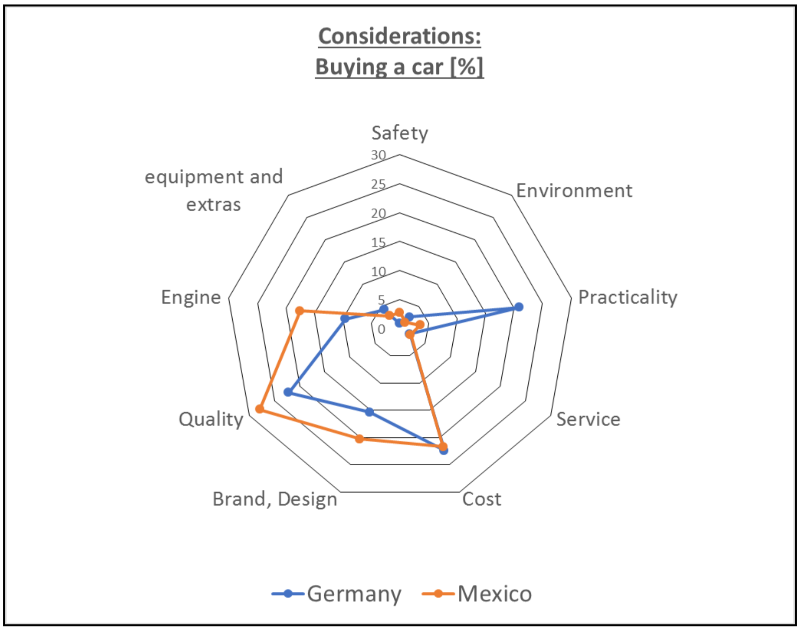


Fig. 1 Considerations for buying a car

In Fig. 1 it can be seen that the two most important values in terms of buying a car are the same in both groups: quality and costs. The third ranking is different: when buying a car, the German respondents pay more attention to the practicality of the car. In contrast the Mexican respondents put more value on the engine and the brand and design as the Germans.

The aspects for service are similar in both countries (Fig. 2). From the German respondents more people

answered that they do not need any extra services than from the Mexican respondents. But in both countries the guarantee on the car is the most important service when owning a car. As also very important the low-cost repairing is mentioned in both countries.

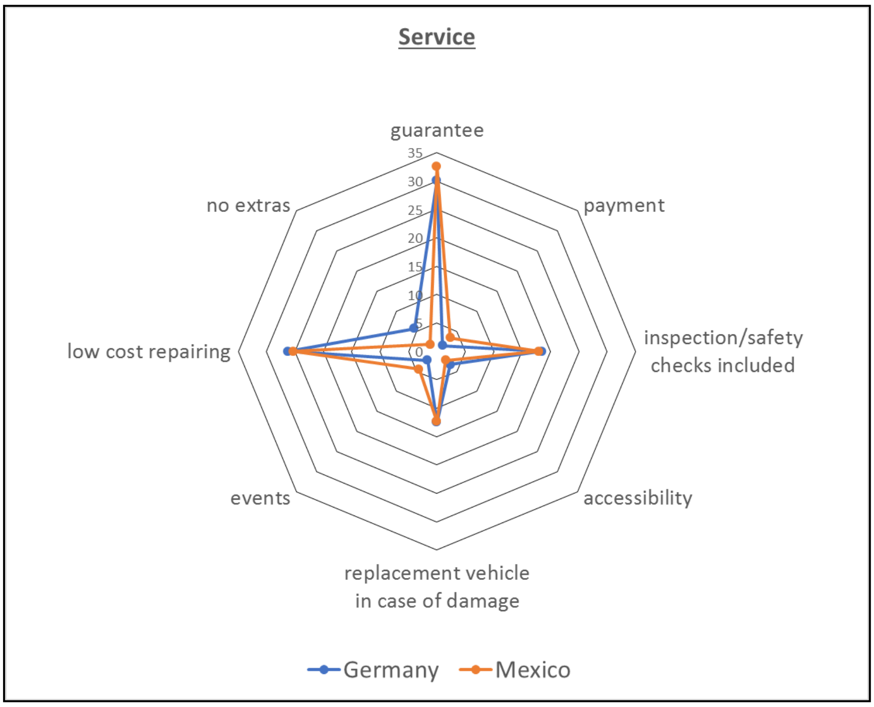


Fig. 2 Service

In addition to the purely technical reasons for the decision to buy an automobile, the future usage structure also plays a major role in the selection of the product. The most frequent destinations by using a car are shown in Table 1a).

Table 1

a) most frequent destinations

Destination [%]	Germany	Mexico
Work/university/school	67,4	87,5
Family/friends	19,7	5,6
Hobby	6,0	2,8
Shopping	4,7	1,4
Holiday	1,3	0,0
Everywhere	0,0	2,8
Do not use cars	0,9	0,0

b) favourite mobility concept

Favourite mobility concept [%]	Germany	Mexico
car (as owner)	67,1	86,1
bus, train, taxi, uber	13,2	6,9
car sharing	10,7	1,4
others (motorbike, bicycle)	9,0	5,6

It can be easily seen that the order of the destinations is the same in both countries. What attracts attention is that less German people use their car for going to work or university. This might have the reason that many Germans use public transportation. Furthermore, no Mexicans answered that they do not use cars at all. The public transportation in Mexico does not offer as many options and opportunities as the public transportation in Germany. That makes the own car more necessary for Mexicans.

The favorite mobility concept of the respondents demonstrates that for Mexican people the own car is more important than for German people. The concept of car sharing like it is known in Germany does not exist in Mexico. Many Mexicans use Uber, because the public transportation plays only a minor role. But even summarized with the usage of Uber the Mexican people use less public transportation and prefer the use of their own car. The reason for this is the security situation in public and the fact that many people are living outside of the city where no public transportation is available.

As the respondents were asked to describe the automotive industry in their country with three words the respondents mentioned a variety of different answers, but some points are mentioned often.

The descriptions that the Germans mentioned most are quality, expensive, innovative and big. The automotive industry in Germany is very important as an employer as well as for the economy so it is very powerful. Furthermore, many respondents mentioned that Germany is leading, the tradition, reliability and the technical high standard. Also, companies like Mercedes-Benz, BMW and Volkswagen are named by many Germans as brands with reputation. In addition to the usability of the vehicle, the automobile in Germany also has the purpose of a status symbol.

Criticized is the lack of flexibility, lobbying and the environmental pollution. The suppliers have to struggle with

the prices and the quality. In Germany there are many regulations regarding the emissions which are politically driven but you can find also funding for e-mobility and developments in autonomous driving and digitalization. The German automotive industry has a great variety of brands, suppliers and concepts that are well-engineered.

The descriptions that the Mexicans mentioned most are low costs, quality, growing and manufacturing. Some people also named it expensive and luxury but on the other hand practical and economic was mentioned, as well as the cheap labor. The Mexican automotive industry is “foreign” because there are no car companies from Mexico.

The diversity is also mentioned, because Mexico has car companies from all over the world. Innovation and development make the Mexican companies competitive. Especially the good local position is attractive, and many companies do outsourcing and fabricate in Mexico. So, the automotive sector in Mexico is big, most of all the production and assembly is mature. In contrast to the Germans the Mexicans call their automotive industry modern and dynamic. No sport cars and many pick-ups are associated with Mexico. Criticized is the corruptness, the lack of regulations and that no cars are designed in Mexico. International companies like Volkswagen are named and traffic is also a problem.

In both countries there are people who place importance on the brand, or that it is a cabriolet or the design. As well the engine, power, acceleration rate and sound take an important part for the driving enjoyment. Others like to have it practical with a good handling, for example sliding doors, easy to park or just simple.

Another big issue for families and workers is the space or many seats, so that it has enough room for the whole family or using it to transport something. But the combination between a family car and still a sporty feeling and appearance is also a deciding factor that has to be considered. Another important issue is a good price-performance-ratio, so that it is cheap or affordable but nevertheless has good quality, features and is reliable. The quality gives a feeling of safety and dependability that is very important for many people. Furthermore, the assistant systems, parking aid and a good sound system are named. The comfort is mentioned by both groups very often. Heated seats are important for many Germans, air condition is very important for Germans and Mexicans. All wheel drive and automatic drive is also a buying criterion for some people. Electric cars and plug-in hybrids are named by both groups, as well as that they like their car to be ecological and economical.

5. Results of the Expert Interviews

THE BIGGEST DIFFERENCES

The biggest differences between the German and the Mexican automotive industry are the different standards, requirements and norms of the two countries. In Germany the laws of Europe are applied, and the Mexican industry is similar to the American industry. This means there are different requirements, for example, for the emissions, the safety and the corrosion resistance of a car. In Germany there are stricter emission regulations than in Mexico and the safety is more important. The A-pillar and the B-pillar, for example, are stronger in European cars and the headrest is more robust. The requirements for the corrosion resistance are also stricter in Europe, which can be shown with the copper accelerated salt spray (CASS) testing. American parts have to be in the chamber for 24 hours without showing any corrosion while German parts have to be in there for 48 hours. Parts for the American and Mexican automotive industry are painted with a primer and then with the color, in Germany the basement has the same color as the part will get in order not to see little scratches.

Considering the future development of both industries one of the biggest differences concerns the e-mobility. The awareness for environmental responsibility in Germany is higher than in Mexico. Not only national but also European law will force the German automotive industry to focus on renewable energy. Mexico does not see the necessity to change their perspective and development. Mexicans attitude towards the environment can be demonstrated in Mexico City were the license plate prohibits to drive one day a week. In order to be able to use their car seven days a week, Mexicans tend to have a second car in Mexico City. Thus, the problem with the air pollution in the metropole is not resolved.

CHANGES IN NEAR FUTURE

There will be more openness from the Mexican government towards foreign companies, providing subvention to set up production sites in Mexico. In the beginning there were only Volkswagen, GM, Nissan, Chrysler and Ford, now also Kia, BMW, Audi and Daimler are located in Mexico. The Mexican automotive industry proves its capability of producing high quality. This will improve its reputation and more and more companies will see Mexico as an opportunity to get high quality at affordable prices. More production sites for similar products will increase the economy of scale inside the industry, thus lowering prices for raw materials and products.

The future automotive industry in Germany will highly be affected by the trend of renewable energy, focusing on e-mobility and possibly on alternative energy sources like F-Cells. Production sites inside Germany will become even more automated using the internet of things and concepts of industry 4.0 with the goal to automate the whole production process from purchase to sale making it a network of intelligent systems. The necessity of automation in Germany is founded in the high labor costs. Since Mexico has a huge number of less educated workers, labor is still affordable, and the costs of automation would be higher. For the same reason Germany will continue to outsource production lines to countries like Mexico.

PRODUCING IN MEXICO

Mexico can be seen as one of the best production sites for the automotive industry worldwide. Half of the raw

materials needed are sourced and produced inside Mexico. High quality steel which is used to build chassis and exterior is produced in the country. The biggest suppliers for interior, exterior, mirrors, chassis and powertrain also have huge subsidiaries in Mexico. Engines and transmissions are produced in Mexico which makes supply distances short and cheap. In total about 70% of the parts of a car could be produced in Mexico. Up to now the steel used for tooling devices is imported from Germany, this might change in the future. Other imported goods are plastics and electrical parts. Considering the market entry, the Mexican car industry is attractive. There is plenty of land available, even in industrial areas, and the prices are low. Mexico offers clusters where producers of raw material, engines as well as assembled parts, come together, building a highly efficient area. Additionally, companies receive submissions from the government to build production sites and provide employment for locals. In Mexico, being a producing industry, a highly educated and efficient workforce is also available.

Up to now Mexico has shown a good production site, focused on assembly and manufacturing, struggling to become more involved into the design part. Some simple parts are already designed in Mexico, but the complex sections are still designed by engineering experts in Germany or the US. Especially considering the high quality for affordable hourly costs, Mexico has a big competitive advantage. The labor turnover is about 3% in the automotive industry and low compared to other industries where it is about 20%.

Environmentally Mexico has some disadvantages depending on the area. Earthquakes and water shortage can become an issue for the production process. In Saltillo, for example, there are huge GM and Chrysler sites but there is few water, so they have to drill down around 60 to 200 meters in order to be able to pump the water up.

Before starting a new business or building a production site in Mexico as a foreign company it is important not only to find a suitable environmentally area, but also to find a local shelter company. This company shows you the way of working in this country, protects you and helps getting established at the market. The cooperation with the shelter company should last until you are established.

PRODUCING IN GERMANY

Germany is worldwide seen as a production site with well-skilled employees and high-quality products. The German knowledge within the automotive industry is based on their experiences and on highly equipped and competent universities. The graduated students have a high potential of developing new techniques and improving current processes to increase the productivity. Furthermore, Europe is driven by investments and innovations and supports new ideas that have potential. The production in Germany uses a lot of modern techniques like robots, for example for welding or precise positioning of parts. The machines are used to make the work more comfortable and secure for the workers. Some processes are therefore completely automated. This is one difference between producing in Mexico and Germany. Almost every process in Mexico is manual or only assisted by machines. German manufacturers grasp at improving productivity and optimized process sequences. This is necessary because the production in nearly every industry in Germany is based on the concept of just-in-time supply. This means that the required parts arrive at the time they are needed which means that the different processes and manufacturers have to be well coordinated. The most important sectors in the automotive industry in Germany are the design and the development. All big and successful German automotive manufacturers have the design and the development of their cars located in Germany even if they have productions sites all over the world. In Germany some suppliers of modules or systems develop their products on their own and sell the whole component to the car manufacturer. One advantage of producing in Germany is the proximity to the development sites and the resulting brief communication channels between them and the manufacturers.

The political background in Germany is stable and there are no environmental impacts that have to be considered. Germany is a country that only has a few raw materials so that many of the materials have to be imported. Furthermore, the high labor costs make it very expensive to produce. Moreover, there are many laws and regulations in Germany that must be observed. Examples for these regulations are environmental laws which include the use and disposal of water, gas and energy. Other laws are for the security and the health of the workers and for the condition of the working machines.

SERVICES AND OFFERS

Buying a car is often a hard decision because it costs a lot of money and you want to have the best you can get for this money. The car manufacturers know this and have special services and offers for the customers. One offer is leasing a car, which means the customer is paying in installments while using the car and after a period of time he is free to give the car back or pay the rest amount to own it. The leasing system is common in Germany but does not exist in Mexico, only employees of car manufacturers can buy a car for similar conditions directly from the manufacturer. In Germany special offers are possible regarding to the guarantee or additional services during the car service if the customer goes to partner workshops of the manufacturer. The companies, either in Germany or Mexico, try to be attractive and try to keep their employees with special conditions for buying their products, fitness offers or childcare facilities. In Mexico, even the employees of suppliers receive preferential treatment, if they buy a car in cash they are entitled to discounts that the manufacturer offers to the supplier.

In terms of services in general you can see employees at the gasoline stations in Mexico that fill the tanks of the cars and also wash the windows of the car. In restaurants there is mostly offered a valet parking service. These services around the automobile are in Germany rarely to find. This is just one example that shows that the Mexican people are accustomed to get good service in everyday life. German people also place importance on good service but in Germany you get good service only in combination with expensive products or at expensive institutions. This could be a

consequence of the high labor costs in Germany compared with Mexico.

CONCEPTS OF MOBILITY

In Mexico for most of the people it is a necessity to have an own car because there is a lack of infrastructure in the public transportation system. The public transportation in Mexico consists mainly of busses which causes traffic problems especially in big cities. It is difficult to estimate if the infrastructure will increase but if it would be better the Mexicans would use more public transportation and less cars. There might be a necessity to possess a car in Germany as well, but this depends on the place where you are living. Nearly every town in Germany has a good infrastructure of public transportation. Only people living in the countryside may need an own car. Owning a car is very expensive in Germany as well as in Mexico. Therefore, a lot of Mexicans prefer to take an Uber instead of having an own car.

6. Conclusions

Geographically Mexico is a very good country to produce cars because it is close to the American market and it has many free trade agreements. They also have less labor costs but still a very good quality of their products. The automotive industry in Mexico mainly consists of producing and manufacturing, only simple parts are designed and constructed by Mexican companies. A disadvantage of producing in Mexico are the environmental impacts like earthquakes and water shortage that can influence the processes. Such influences cannot be found in Germany. The German automotive industry stands for high quality and safety as well as for precise constructions and remarkable design. The big German automotive manufacturers have a lot of production sites all over the world, but the design and development are still located in Germany in the headquarters of the companies. Producing in Germany is very expensive because the labor costs are high, as well as the degree of technologisation and automation and a lot of regulations to protect the workers and the environment. The German automotive manufacturers are looking forward to the future and are therefore investing in developing alternative driving technologies. E-mobility is one of these technologies which are supported by the government. The Mexican government is not interested in alternative driving technologies so far, but they have changed the law of electricity which will lead to a growing interest in e-mobility of Mexican companies.

References

1. Germany Trade and Invest: Automotive Industry - Germany - The World's Automotive Hub of Innovation [online cit.: 2017-09-18]. Available from: http://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Mobility/automotive.html. www.gtai.de/.../industry-overview-automotive-industry-en.pdf
2. Reuters [online cit.: 2017-09-20]. Available from: https://www.reuters.com/article/us-germany-economy/emissions-scandal-is-a-risk-to-german-economy-ministry-idUSKCN1B00U5
3. PwC México: Guide to develop and invest in the Mexican automotive sector [online cit.: 2017-09-20]. Available from: https://www.pwc.de/de/internationale-maerkte/assets/doing-business-mexico-automotive.pdf
4. Handelsblatt [online cit.: 2017-09-17]. Available from: http://www.handelsblatt.com/my/unternehmen/industrie/mexikos-autoindustrie-produktion-und-exporte-steigen-deutlich-an/19230384.html?ticket=ST-1177656-aUZCePwL3WgbkAEhBohW-ap2
5. Welt [online cit.: 2017-09-17]. Available from: https://www.welt.de/wirtschaft/article136175811/Das-ewige-Sehnsuchtsland-deutscher-Autobauer.html

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Long-Term Development of Transport Emissions in the Czech Republic

B. Antonová

University of Pardubice, Faculty of transport engineering, Studentská 95, Pardubice 532 10, Czech Republic,
E-mail: barbora.antonova@upce.cz

Abstract

Transport is an important element of sustainability but, on the other hand, it causes congestion, accidents, smell, noise, air pollution, health effects etc. This article will focus on the environmental pillar of sustainable transport, specifically on transport emissions. The aim of this paper is to analyze the long-term development of greenhouse gas emissions from transport in the Czech Republic. The paper shows not only trends from last years but although prediction over next five decades will be show in the paper. The long-term development is then compared with the goals of EU transport policy.
KEY WORDS: *transport, greenhouse gases, sustainable development*

1. Introduction

Sustainable transport has become a widely discussed topic in recent years. Generally we can state that sustainable development is an important factor in the development of individual economies. Sustainable transport is characterized as a transport that does not endanger public health or ecosystems, but at the same time it provides for transport demands so that competitiveness and regional development are supported [1]. Sustainable development concept is based on three pillars-the economic pillar, the environmental pillar and the social pillar [2]. The source accentuates the importance of the environmental pillar. Production of greenhouse gases (GHG) is one of the most frequently discussed issues that fall under this pillar in the area of transport; in particular it is the production of carbon dioxide (CO2). CO2 is considered to be the main cause of global warming [3-7]. Transport as a sector is specific by the fact that unlike in other national economy sectors where GHG emission are being reduced, in transport, in particular in individual car transport, CO2 [5] emissions are growing. GHG emissions reduction should therefore become priority number one, however, on the other hand it is essential to mention that this is in contradiction with growing global energy demands [4]. The key factor here is to fully realize that next to the technical aspects also transport behaviour has to change [7-9].

Considering indirect and long-term impacts is very important for the area of sustainable development planning. Thereby analyses of public policies and of related documents are of key importance. On the EU level the key document for this area is White Book of Transport Policy (White Book: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system; hereinafter the White Book) [10]. This White Book is based on the European Commission's vision for transport in year 2050 titled Transport 2050 [11]. On the general level it is essential to reduce GHG emissions by 80%-95% compared to year 1990 level [10] by year 2050. To be able to reach this objective it is essential to cut GHG emissions from the transport area by at least 60% compared to year 1990 level by year 2050. An intermediate stage on this path towards reaching this goal is reduction of GHG emissions by 20% compared to year 2008 level by year 2030 [10]. The Czech Republic (CR) reflected this White Book strategy in its national transport strategy and in year 2013 the CR government passed a document "Transport Policy of the Czech Republic for 2014-2020 with the Prospect of 2050" [12].

The objective of this article is to analyse long-term development of GHG emissions produced by transport in the CR. This analysis shall be executed in two steps:

1. An analysis of the development of GHG emissions produced by transport in the period 1990–2015.
2. Evaluation of GHG emissions development in the context of the goals set in the White Book for years 2030 and 2050. A prediction of future development of this indicator was done under this step.

2. Methods

The following models of Box-Jenkinson's methodology have been used for the prediction of the development of GHG emissions. The B-J methodology is based on both probability and stochastic analyses of a time series where the time series values y_t are explained by the preceding or the shifted values of the time series and by its random components [15]. The basic element in the random quantities [15]. The B-J methodology works with various forecast models; however, most often with Autoregressive Integrated Moving Average Models, that are marked as ARIMA (p, d, q) models and these models are applied for those time series in which there are not any seasons [15]. In case the relevant time series has seasons then, according to the author, for the prediction of the time series is used a more general model – model SARIMA. This model, next to a trend, includes also the above-mentioned seasons [15].

ARIMA(p, d, q) models are defined by the following formula [16]:

$$y_t = \phi_0 + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p} + \varepsilon_t - \vartheta_1 \varepsilon_{t-1} - \vartheta_2 \varepsilon_{t-2} - \ldots - \vartheta_q \varepsilon_{t-q}\,, \tag{1}$$

Error! Reference source not found.here p – the number of autoregressive terms; q – the number of lagged error terms; ϕ – the coefficients of the autoregressive terms; ϑ – coefficients of the moving average terms and ε_t – white noise process.

Box-Jenkinson‘s methodology includes four steps [16]:

1. Model Identification
2. Guesstimate of Model Parameters
3. Model Diagnostic
4. Calculation of Prediction.

Correct combinations of parameters p, d and q values are selected in the framework of model identification. Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) are consequently applied for the identification of the model, graphs of these functions respectively. Prior to the calculation of ACF itself and PACF itself estimates it is important to identify any presence of a trend and of „outliers“ observations. Further it is essential to evaluate if it is or if it is not essential to execute transformation stabilizing the range of scatter. However, in the majority of cases it is sufficient to utilize a suitable level of time series differentiation. In this model the desired level of differentiation is labelled as d.

The estimation of parameters for the model that includes estimation of auto regression parameters and estimation of moving average is executed by means of the method of the smallest squares, or possibly by the non-linear method of smallest squares or by the method of maximum credibility that is used most often. The objective of the maximum credibility method is estimation of parameters $\phi_1,\ldots,\phi_p;\vartheta_1,\ldots,\vartheta_q;\mu$ and σ_η^2, where the credibility function reaches its maximum (2), where T is the number of observations after differentiation (3).

$$f\left(a\middle|\phi,\mu,\vartheta,\sigma_\varepsilon^2\right) = L\left(\phi,\mu,\vartheta,\sigma_\varepsilon^2\right) = \left(2\pi\sigma_\varepsilon^2\right)^{-\frac{T}{2}} \cdot \exp\left(-\frac{1}{2\sigma_\varepsilon^2}\sum_{t=1}^{T}\varepsilon_t^2\right); \tag{2}$$

$$T = n - d\,. \tag{3}$$

In the framework of model diagnosis the following is executed: testing of stationarity and seasonality by means of Dickey-Fuller’s test, testing of estimated parameters by means of t-tests, testing of the model as a whole respectively [17]. Consequently residua of the estimated model are tested by means of correlation analysis; in concrete words it is tested whether they might be statistically significant and represent so called white noise process (ε_t) [16]. This represents a sequence of independent random values with the same distribution with zero mean value and with constant spread and that means that errors are distributed evenly according to relations (4), (5) and (6). ε_t is characteristic by its following values of the auto-covariance (7), autocorrelation (8) and partial autocorrelation functions (9) [18].

$$E\left(\varepsilon_t\right) = 0 \text{ for } t = 1,2,\ldots,n; \tag{4}$$

$$D\left(\varepsilon_t\right) = \mathrm{var}\left(\varepsilon_t\right) = \sigma^2 \text{ for } t = 1,2,\ldots,n; \tag{5}$$

$$\gamma_k = C\left(\varepsilon_t, \varepsilon_{t-k}\right) = 0\,,\ k \neq 0\,; \tag{6}$$

$$\gamma_k \begin{Bmatrix} \sigma_{\varepsilon_t}^2 & k = 0 \\ 0 & k \neq 0 \end{Bmatrix}; \tag{7}$$

$$\rho_k \begin{Bmatrix} 1 & k = 0 \\ 0 & k \neq 0 \end{Bmatrix}; \tag{8}$$

$$\phi_{kk} \begin{Bmatrix} 1 & k = 0 \\ 0 & k \neq 0 \end{Bmatrix}. \tag{9}$$

In case all conditions are fulfilled, it is possible to use the estimated model for the prediction of time series. In the opposite case it is essential to come back to the model identification step and to repeat the entire process.

In case of some time series there may happen that two or more models suitable for these time series can be identified. The most suitable model is always the one that minimizes the criteria value. It is possible to use the following criteria: Akaike Information Criterion (AIC) (10) [19, 20], The Akaike Information Criterion with a correction, (AICc) (11) [21, 22] and Bayesian extension of Information Criterion (BIC) (12) [23]. Criteria do not cause any distortion as for instance the determination index in classical regression.

$$AIC(M) = T \ln \hat{\sigma}_{\varepsilon}^{2} + 2M \,, \tag{10}$$

here T – the number of observations after differentiation, M – the number of parameters $M = p + q$, $\hat{\sigma}_{\varepsilon}^{2}$ – residual scattering of the observed time series.

$$AICC(M) = \ln \hat{\sigma}_{\varepsilon}^{2} + \frac{\dfrac{2M}{1 - \dfrac{(M+1)}{T}}}{T} \,; \tag{11}$$

$$BIC(M) = T \ln \hat{\sigma}_{\varepsilon}^{2} - (T - M) \ln\left(1 - \frac{M}{T}\right) + M \ln T + M \ln\left(\frac{\dfrac{\hat{\sigma}_{x}^{2}}{\hat{\sigma}_{\varepsilon}^{2}} - 1}{M}\right), \qquad 12)$$

here $\hat{\sigma}_{X}^{2}$ – selection scattering of the analysed time series.

The probability calculation phase includes in itself also the calculation of the forecasts and of their reliability intervals. General forecast $\hat{X}_{n}^{*}(h)$ is illustrated by the relation (13), where h is the horizon of the forecast [16]. In case that $h > p$ and $h < q$, the forecast can be written in the following way (14). The reliability intervals for forecast of time series $\hat{X}_{n}^{*}(h)$ is calculated by relation (15) where is valid (16) [16].

$$\hat{X}_{n}^{*}(h) = \hat{\phi}_{1}\hat{X}_{n}^{*}(h-1) + \ldots + \hat{\phi}_{h}\hat{X}_{n}^{*} + \ldots + \hat{\phi}_{p}\hat{X}_{n-p+h}^{*} - \hat{\vartheta}_{h}\hat{\varepsilon}_{n} - \ldots - \hat{\vartheta}_{q}\hat{\varepsilon}_{n-q+h} \,; \tag{13}$$

$$\hat{X}_{n}^{*}(h) = \hat{\phi}_{1}\hat{X}_{n}^{*}(h-1) + \ldots + \hat{\phi}_{p}\hat{X}_{n}^{*}(h-p) \,; \tag{14}$$

$$C_{n} = \hat{X}_{n}^{*}(h) \pm c\sqrt{\left(\sum_{j=0}^{h-1}\hat{\psi}_{j}^{2}\right)}\hat{\sigma}_{\varepsilon} \,; \tag{15}$$

$$\sum_{j=0}^{\infty}\psi_{j}^{2} = \infty \,. \tag{16}$$

3. The Development of GHG Emissions Produced by Transport in the CR in the Period 1990–2015

The development of GHG emissions produced by transport in the CR (measured in million tons CO2 equivalent, MT of CO2eq) illustrated in Fig. 1, can be grouped into three periods.

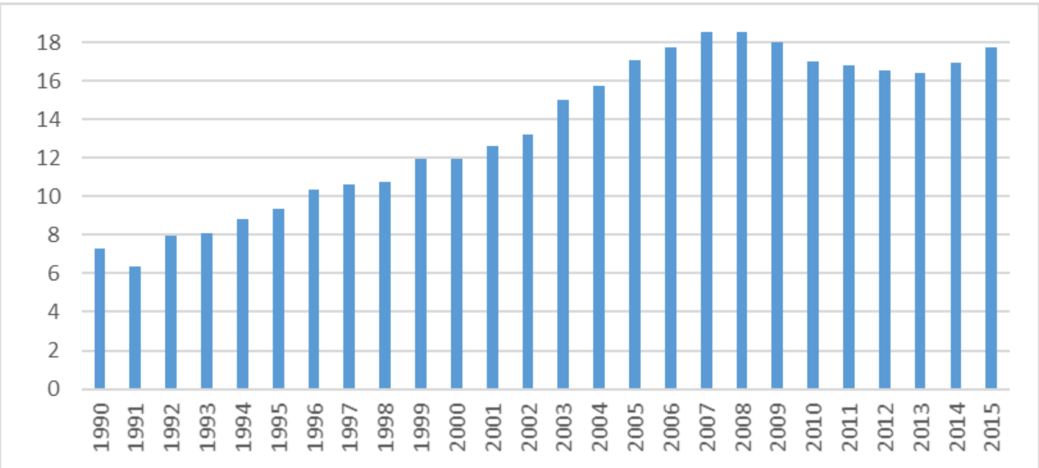


Fig. 1 The development of GHG emissions produced by transport (MT of CO2eq) [24]

In years 1990–2007 (with the exception of year 1991 – decline by 0,89 MT of CO2eq and 2000 – decline by 0,05 MT of CO2eq) GHG emissions increased 256,6%; from value 7,28 MT of CO2eq in year 1990 up to value 18,69 MT of CO2eq in year 2007. The biggest increment in emissions was in years 2003 (1,77 MT of CO2eq) and 1992 (1,58 MT of CO2eq). In year 2007 transport produced the largest volume of GHG emissions – 18,69 MT of CO2eq - which

represents nearly 2,6multiple of the 1990 value. In the second period, that means in years 2008-2013, GHG emissions showed a declining trend; from value 18,56 MT of CO2eq in year 2008 the volume of emissions declined by 11,4 % and reached the volume of 16,43 MT of CO2eq in year 2013. The largest year-on-year decline (1,01 MT of CO2eq) was observed in the period 2009 to 2010. In the last two observed years we can see a growing trend-the volumes grow; in year 2014 by 0,54 MT of CO2eq up to the volume of 16,97; in year 2015 by 0,78 MT of CO2eq up to volume of 17,75 MT of CO2eq. In year 2015 GHG emissions got up to the level of year 2006.

4. Prediction

For time series modelling, R software (the R Project for Statistical Computing) was used. In R software all steps required in ARIMA modelling are contained in a function auto.arima(), which returns best ARIMA model according to either AIC, AICc or BIC value. The function conducts a search over possible model within the order constraints provided. Considering the emission data are annual and there appears to be no seasonal pattern, a non-seasonal ARIMA model was selected. For modelling there was selected ARIMA(2,1,0) model with non-zero mean or just AR(2) model including intercept:

$$y_t = 0{,}1295\Delta y_{t-1} - 0{,}5617\Delta y_{t-2} + \varepsilon_t\,; \tag{17}$$

$$\Delta y_t = y_t - y_{t-1}\,, \tag{18}$$

here Δy_t – the first time difference (18):

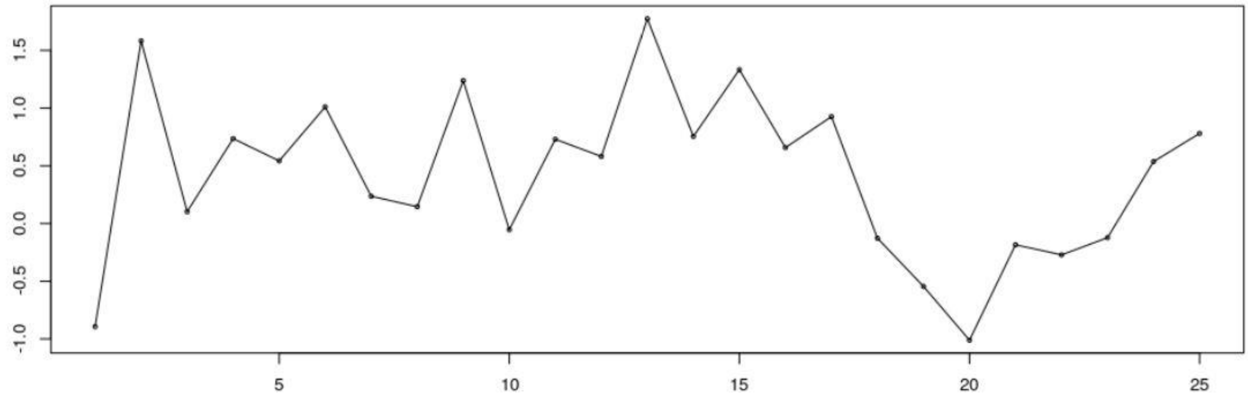


Fig. 2 The line chart of the analysed time series

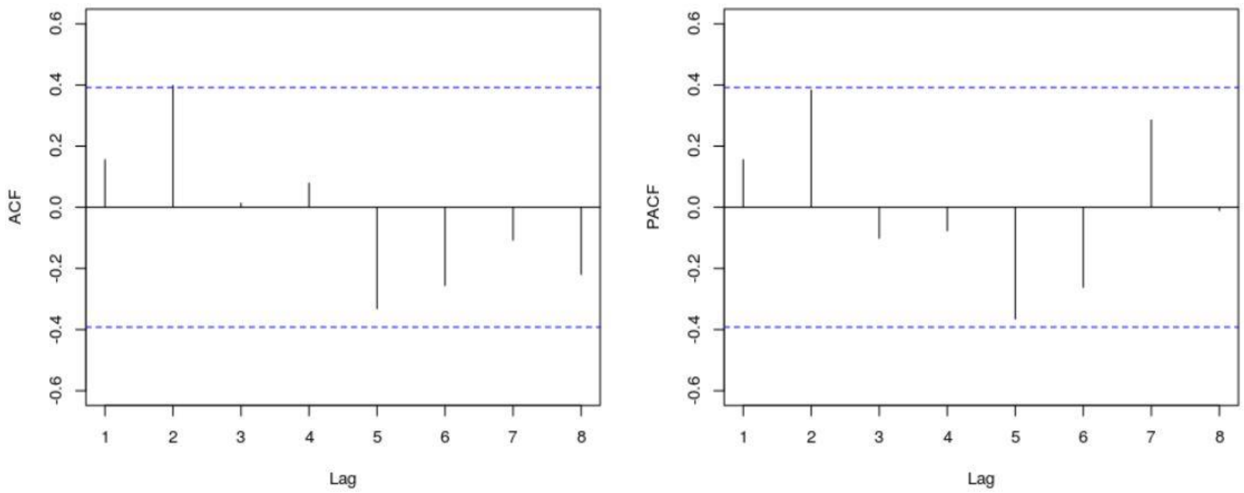


Fig. 3 ACF and PACF functions visualisation

In Figs. 2 and 3 there are illustrated basic characteristics of a time series. Fig. 2 shows basic line chart of the analysed time series (their differences respectively). In Fig. 3 we can see visualisation of ACF and PACF functions. These functions can be utilized for identification of a suitable model and they are on top of this also a suitable model tool for evaluation of time series stationarity.

In case of the observed time series the suitable model was selected based on information criteria (Table 1). BIC was taken as the key decision point. ACF and PACF functions were considered primarily for verification of the hypothesis of stationarity. In our research however the main tool for confirmation of the stationarity hypothesis remains

to be tests specifically designed for these purposes. One of the most important indicators of no-stationarity time series is that majority of ACF and PACF values oscillate around the value 1, however in our case this does not represent any problem.

Table 1

Values of the criteria

AIC	56,14
AICc	57,28
BIC	59,8

The result of the prediction of GHG emissions development with time is illustrated in numbers in Table 2 and it is graphically illustrated in Fig. 4. Concrete values of the prediction of GHG development, calculated by means of ARIMA model, are defined by the top and the bottom borderlines of the given confidentiality interval. Calculations were done for reliability levels of 80%.

Tab.2 summarizes forecasted values for key years 2030 and 2050 to which the transport policy goals in the area of GHG emissions are related.

Table 2

GHG emissions produced by transport in the CR – outputs of the ARIMA model (MT of CO2 equivalents)

Year	The mean Value	Low 80	High 80
2030	20,34	11,96	28,72
2050	20,47	1,96	38,99

Fig. 4 shows forecast of development of GHG emissions calculated using the ARIMA model. Charts are executed separately for the forecast till year 2030 and for year 2050. Results for HGH emissions forecast for year 2030 show values with higher level of reliability.

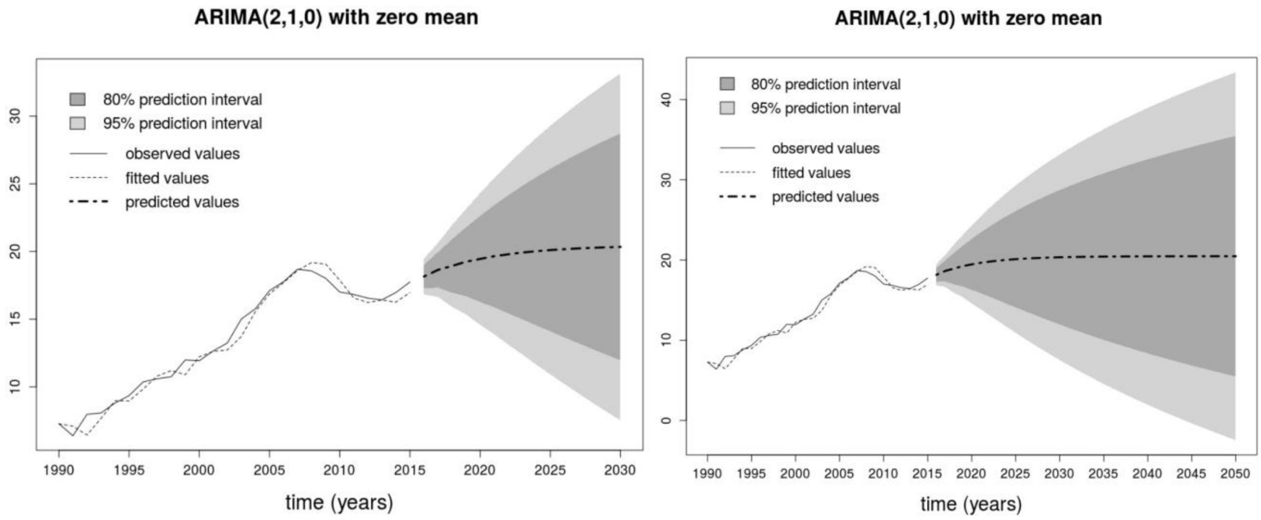


Fig. 4 The forecast till year 2030 and 2050

5. Conclusions

A development analysis of GHG emissions produced by transport between years 1990 and 2015 was executed in this article. In this period there was a significant increase in the total volume of GHG emissions, however this increase is not continuous throughout the period. Based on the data from the observed period a prediction of possible GHG emissions development till the year 2050 was made. The prediction was created by using the Box-Jenison's methodology, specifically using the ARIMA model. The results of the prediction do not show any decline which was set in the White Paper. It is important to mention that this prediction is based on the current situation; however, it takes into account many deviations from the current state probably caused by introduction of suitable measures to reduce GHG emissions or by increasing GHG emissions due to unexpected effects.

According to the White Paper provision, at least 60% reduction of GHG emissions is necessary to be made in the transport sector till the year 2050 compared to the year 1990, which represents a value of 3,14 MT of CO2eq. Reduction of GHG emission by 20% below the level of year 2008 (representing the value of 14,85 MT of CO2eq) is an intermediate stage in achieving the ultimate goal. It is impossible to reach this intermediate stage in case that no

measures for a GHG emissions reduction would be introduced (the median value calculated by ARIMA model for the year 2030 is 20,34 MT of CO2eq). Meeting the goals set for year 2050 requires a much more dramatic reduction of GHG emissions, especially due to the fact that the above mentioned 60% GHG emissions reduction is related to year 1990 (when the level of GHG emissions was less than half of the year 2008 level). GHG emissions should be perceived as a major problem of contemporary society which is needed to be solved for human future on the Earth, so all the scientific skills should be fully involved.

References

1. The Institution of Engineers. 1999. Sustainable transport: responding to the challenges, sustainable energy transport taskforce report. Australia: The Institution of Engineers.
2. Subcommittee of the Transportation Research Board. 2008. Sustainable transportation indicators. Wahington: Subcommittee of the Transportation Research Board.
3. **Espinoza, A.; Bautista, S.; Narváez-Rincón, P.C.; Camargo, M.** 2017. Sustainability assessment to support governmental biodiesel policy in Colombia: A system dynamics model, Journal of Cleaner Production 141: 1145-1163.
4. **Nocera, S.; Cavallaro, F.** 2014. A methodological Framework for the economic evaluation of CO2 emissions from transport, Journal of Advanced Transportation 48(2): 138-164.
5. **Friman, M.; Larhult, L.; Gärling, T**. 2013. An analysis of soft transport policy measures implemented in Sweden to reduce private car use, Transportation 40(1): 109-129.
6. **Black, W.R.** 2010. Sustainable Transportation Problems and Solutions. New York: Guildford Press, 299 p.
7. **Chapman, L.** 2007. Transport and climate change: a review, Journal of Transport Geography 15: 354-367.
8. **Nielson, L.; Khan, J.; Anderson, F.; Klintman, M.; Hildingson, R.; Kronsell, A.; Pettersson, F.; Palsson, H.; Smedby, N**. 2013. I Ljuset av framtiden Styrning mot nollutsläpp ar 2050. Lund: Lunds universitet.
9. **Moriarty, P.; Honnery, D.** 2013. Greening passenger transport: a review, Journal of Cleaner Production 54: 14-22.
10. European Commission. 2011. White Paper: Roadmap to a single transport area – Towards a competitive and resource efficient transport system. Brussels: European Commission, 31 p.
11. European Commission. 2011. Transport 2050: Commission outlines ambitious plan to increase mobility and reduce emissions. Brussels: European Commission, 2 p.
12. Ministry of Transport. 2012. The transport policy of the Czech Republic for 2014 – 2020 with the prospect of 2050. Prague: Ministry of Transport, 59 p.
13. **Lam, D.** 2013. Time Series Modelling of Monthly WTI Crude Oil Returns. United Kingdom: University of Oxford, 46 p.
14. **Pham, H.** 2006. Springer Handbook of Engineering Statistics. United Kingdom: Springer, 1120 p.
15. **Vu, K.M.** 2007. Optimal Discrete Control Theory: The Rational Function Structure Model. Ottawa: AuLac Technologies, 488.
16. **Box, G.E.P.; Jenkins, G.M.** 1970. Time series analysis: Forecasting and control. San Francisco: Holden-Day, 746 p.
17. **Dickey, D.A.; Fuller, W.A.** 1979. Distribution of the estimators for autoregressive time series with a unit root. Journal of American Statistical Association 74(266): 427-431.
18. **Artl, J.; Artlová, M.** 2007. Ekonomické časové řady. Prague: Grada, 285 p.
19. **Akaike, H.** 1969. Fitting autoregressive models for prediction, Annals of the Institute of Statistical Mathematics 2(22): 217-243.
20. **Akaike, H.** 1974. A new look at the statistical model indentification, IEEE Transaction on Automatic Control 19(6): 716-723.
21. **Hurvich, C.M.; Tsai, Ch.L.** 1989. Regression and time series model selection in small samples, Biometrika 76(2): 297-307.
22. **Hurvich, C.M.; Tsai, Ch.L.** 1991. Bias of the corrected AIC criterion for underfitted regression and the time serie models, Biometrika 73(3): 499-509.
23. **Akaike, H.** 1979. A bayesian extension of the minimum AIC procedure of autoregressive model fitting, Biometrika 66(2): 237-242.
24. Greenhouse gas emissions from transport [online cit.: 2018-05-10]. Available from: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tsdtr410&plugin=1

Applying Remotely Piloted Aircraft Systems for Correcting Electronic Chart Data and Ensuring Safe Navigation

A. Urbahs[1], D. Goreļikovs[2]

[1]*Institute of Aeronautics, Riga Technical University, Kaļķu street 1, Latvia, E-mail: Aleksandrs.Urbahs@rtu.lv*
[2]*Institute of Aeronautics, Riga Technical University, Kaļķu street 1, Latvia, E-mail: Dmitrijs.Gorelikovs@rtu.lv*

Abstract

The article proposes a solution to the problem of operative data collection for correcting electronic chart data and ensuring safe navigation. A subsystem for obtaining cartographic data with the help of the Remotely Piloted Aircraft Systems **(**RPAS) has been developed.
On the basis of data received from RPAs, it is possible to create a draw layer for an electronic chart with new coordinates of objects. Creation of such layers will make it possible to objectively evaluate the situation taking into account possible parameter changes for selected key objects. In case of continuous parameter change, for example, the change of shoreline coordinates, this layer is sent to a hydrographic service for introducing changes to the official electronic chart. When using the RPAS, the system will allow to track changes in real time, which at present is possible only with the help of space satellites.
KEY WORDS: *electronic chart data, ensuring safe navigation, electronic chart data correction, remotely piloted aircraft systems*

1. Introduction

Navigation of vessels, as the most important component of navigation, is governed by instruments issued by the International Maritime Organization (IMO) and by national regulations developed by the Maritime Administration. The main commercial navigation aids have to be certified to comply with international operational standards. Safety requirements applicable to the building, equipment and operation of vessels are reflected in particular in the SOLAS (Safety of Life At Sea) Convention [1].

At present, the main means of officially approved electronic navigational cartography is ECDIS or Electronic Chart Display and Information System that complies with both national and international requirements.

In 2009, the IMO adopted requirements on the mandatory installation of ECDIS systems on all merchant ships over 3000 GT and passenger ships over 500 GT (Fig.1). At present, all new cargo ships and tankers with a capacity of over 3000 gross tons and all passenger ships over 500 gross tons have to be equipped with electronic chart systems in compliance with the requirements of the SOLAS Convention [1].

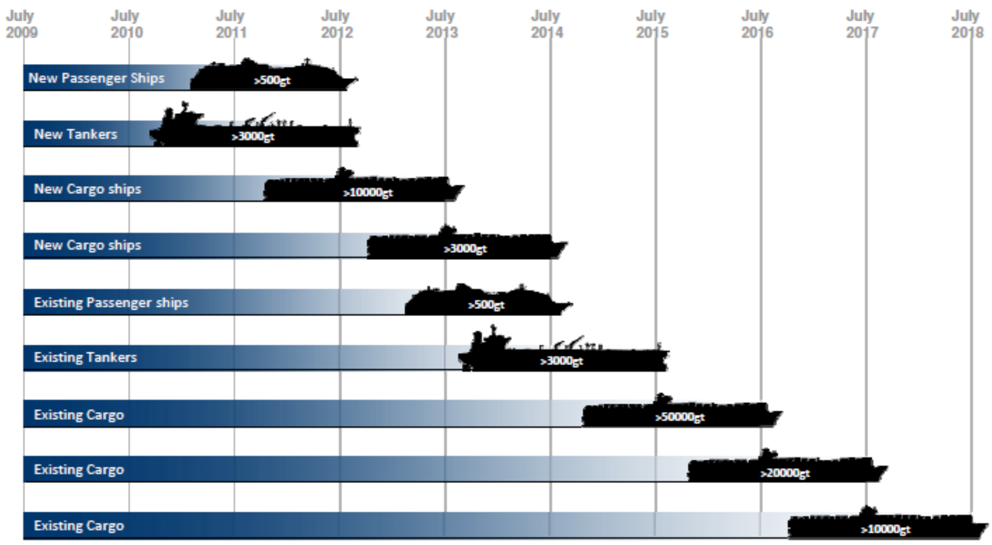


Fig. 1 Cargo carrying capacity of modern sea vessels

In accordance with the SOLAS Convention (1974), since 2002 the ECDIS has been included in the list of marine navigation equipment (Rule 19) and can be used for executive plotting. It was first officially announced in the IMO Resolution of 1995. This resolution states that if there is ECDIS with a collection of official ENC (Electronic Navigation

Charts) with correction on board of the vessel, the system can be regarded as a legal equivalent to paper charts [2]. ENC has to include all cartographic information necessary for ensuring navigational safety; besides, ENC may include additional data, which are not usually shown on marine maps and contained in pilots and other navigational aids, and which are necessary for maritime navigational safety. Official ENCs are charts developed by a state's hydrographic organization to be used in ECDIS by applying S-57 – a basic electronic chart format defined by the International Hydrographic Organization (IHO) and intended for data exchange among hydrographic services, agencies and manufacturers of cartographic products and systems [3].

Ensuring the accuracy and timeliness of ENC correction is a responsibility of national hydrographic organizations. Cartographic information has to correspond to the data from the latest edition published by a state's national Hydrographic Service, as well as to the relevant IMO requirements. For example, in Latvia, the Hydrographic Service of the Maritime Administration of Latvia is a national coordinator: this is an institution authorized by the government to collect and receive information about changes in the condition, parameters and coordinates of navigational objects. The collected information including electronic chart corrections has to be analysed and sent to vessels and coastal services. Unmanned aerial vehicles (RPA) can serve as an effective tool for the quick collection of accurate information for correcting charts [4-6]. Paper [7] describes the functioning of the cartographic information collection system for navigation by using the RPA. This work analyses the operation algorithms of the separate subsystems of the above mentioned system.

2. Practical Implementation of the Cartographic Information System

To identify monitor objects (buoys, lighthouses, etc.), an image recognition subsystem is used (Phase 1 [7]). The subsystem allows to identify the presence of certain objects in the image as well as to calculate the relative coordinates of the centres of these images. The results of recognition are reflected in a table containing the location coordinates of key monitor objects (Figs. 2 and 3).

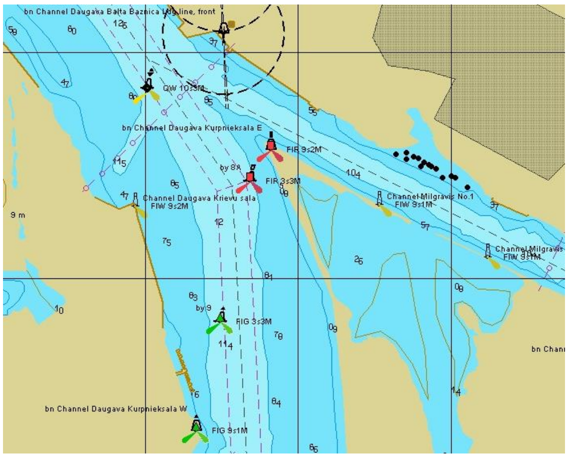


Fig. 2 Original electronic chart for a specified area

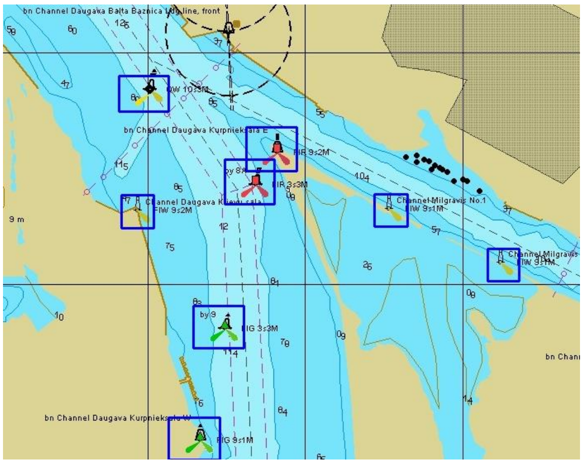


Fig. 3 A processed chart after determining the location of monitor objects (rectangles)

After identifying monitor objects, it is necessary to make an RPA flight plan and determine flight parameters (flight range, speed, altitude), as well as the quality of photography, intensity of framing photography, etc.

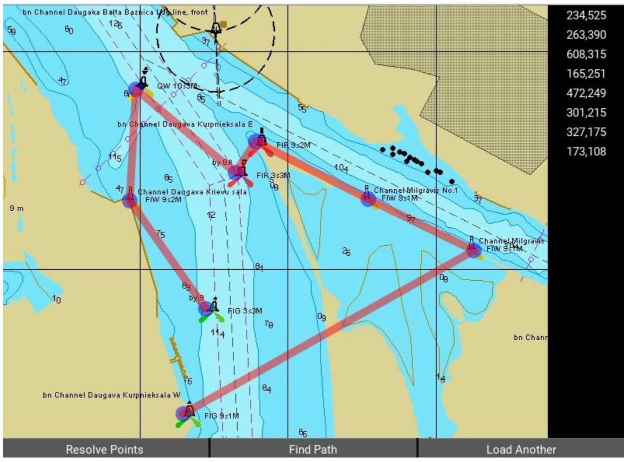


Fig. 4 The optimal flight plan for the monitoring of specified objects

To determine the flight plan, it is required to use an algorithm allowing to photograph a real layout of the specified number of objects in minimal time during the flight. For this purpose, a subsystem calculating an optimal flight plan for the identified objects is used. In the process of creating this subsystem, a comparison of various algorithms of optimal flight plan development was carried out by using graph theory from the point of view of calculation time optimality and the required resources. The subsystem uses the methods of dynamic programming [8] that make it possible to make the optimal flight plan based on object coordinates. An example of the result of subsystem implementation for a specified area (Fig. 1) is presented in Fig. 4.

For the comparison of a real and cartographic object locations, which have been received in the process of implementing Phase 1 and Phase 4 [7], a subsystem for transferring coordinates from bitmap image into World Geodetic System 1984 Datum (WGS84) is used. Such a transfer is mandatory for official charts used in ECDIS [9].

The algorithm we have developed for the created subsystem automatically recalculates object coordinates from the bitmap image (where coordinates are presented in pixels) into the geodetic coordinate system WGS84. Moreover, to calculate the coordinates of objects the coordinates of which may change (for example, buoys), it is possible to use the coordinates of key objects that cannot change their coordinates (for example, lighthouses). Key objects can be identified by their position on the shore, i.e. in an area with a colour gradient differing from the sea surface by colour. Besides, for manual correction, the key points of identified objects can be set by the operator who will enter their coordinates in WGS84. The operation of the subsystem for the automatic calculation of coordinates is presented in Figs. 5 and 6.

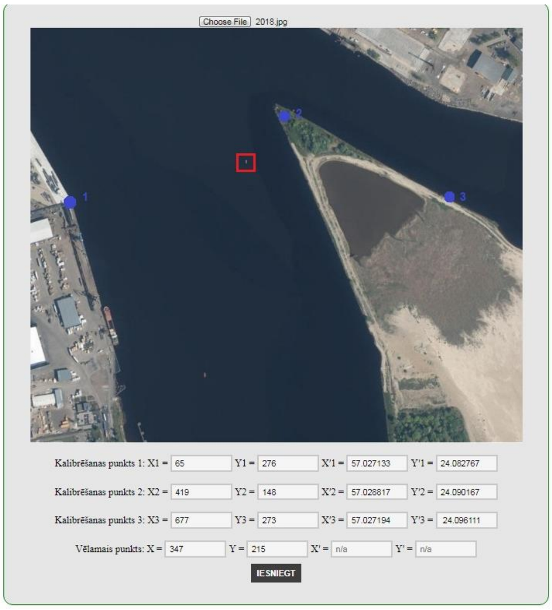
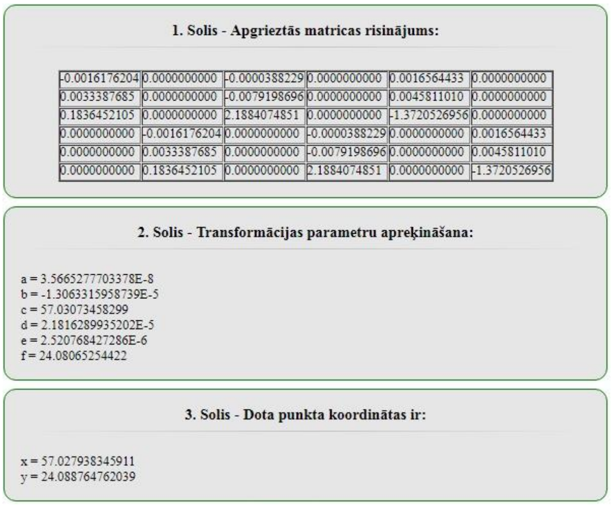


Fig. 5 Setting of key points (blue markers) with coordinates by the operator for the calculation of the WGS84 coordinates of the identified buoy (red marker)



1. Solis - Apgrieztās matricas risinājums:

-0.0016176204	0.0000000000	-0.0000388229	0.0000000000	0.0016564433	0.0000000000
0.0033387685	0.0000000000	-0.0079198696	0.0000000000	0.0045811010	0.0000000000
0.1836452105	0.0000000000	2.1884074851	0.0000000000	-1.3720526956	0.0000000000
0.0000000000	-0.0016176204	0.0000000000	-0.0000388229	0.0000000000	0.0016564433
0.0000000000	0.0033387685	0.0000000000	-0.0079198696	0.0000000000	0.0045811010
0.0000000000	0.1836452105	0.0000000000	2.1884074851	0.0000000000	-1.3720526956

2. Solis - Transformācijas parametru apreķināšana:

a = 3.5665277703378E-8
b = -1.3063315958739E-5
c = 57.03073458299
d = 2.1816289935202E-5
e = 2.520768427286E-6
f = 24.08065254422

3. Solis - Dota punkta koordinātas ir:

x = 57.027938345911
y = 24.088764762039

Fig. 6 The result of coordinate calculation in text format

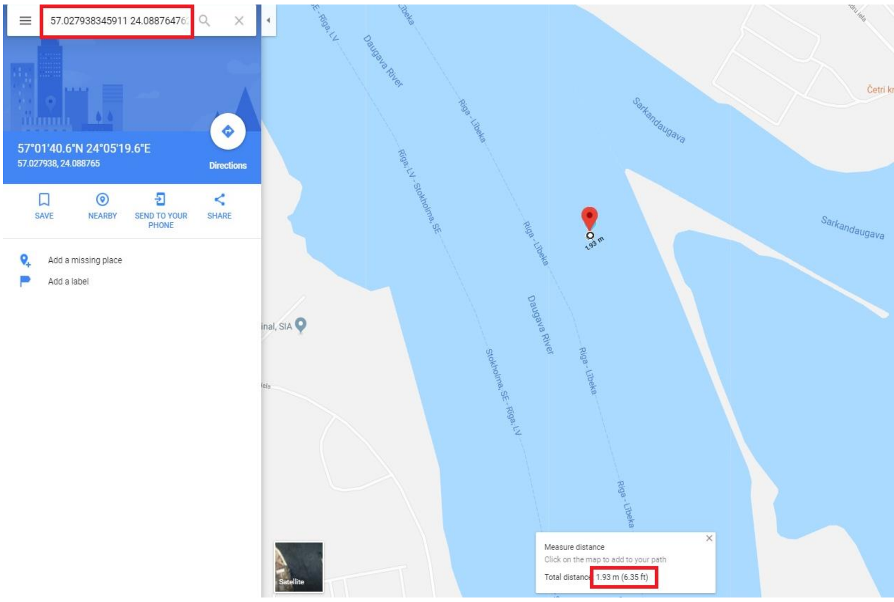


Fig. 7 Comparison of the obtained current coordinates of the object with the previous coordinates marked on the electronic chart

The calculated coordinates are compared with the object reference coordinates on the electronic chart. If the difference is greater than the value set by the operator, the system alerts of the position deviation for a certain object. An example of comparing the results of the previous calculation of object (buoy) position in the photo and its real coordinates is graphically shown (Google Map) in Fig. 7. The difference in coordinates is both visualized and represented numerically. The difference in object coordinate values in the considered example is less than 2 metres.

3. Conclusion

A system of collecting cartographic information for navigation with the help of RPA system has been developed. This system can simplify and cheapen the compulsory information acquisition procedure for government institutions responsible for providing cartographic data. Moreover, the response time is reduced to the time of inspection of key points by the RPA. Taking into consideration the inexpensive cost of this procedure, the frequency of information acquisition is determined by the operator and may reach several flights a day. When using several RPAs, the system will allow to track changes in real time for large geographical areas, which presently is possible only through satellite observation. In addition, the expenditures on satellite observation and the proposed RPA system may differ considerably.

References

1. International Maritime Organization 2012, International Convention for the Safety of Life at Sea (SOLAS), London: Consolidated Edition.
2. International Maritime Organization, Regulation V/19 of the 1974 IMO SOLAS Convention.
3. International Maritime Organization 1999, Resolutions A.817 (19), Performance standards for electronic chart display and information systems (ECDIS), London.
4. **Urbahs, A.; Jonaite, I.** 2013, Features of the use of unmanned aerial vehicles for agriculture applications . Aviation, ISSN 1648-7788 print/ISSN 1822-4180 online, 2013, Volume 17, Nr.4, 170-175 pp. DOI: 10.3846/16487788. 2013.861224.
5. **Urbahs, A.; Žavtkēvičs, V.** 2017, Remotely Piloted Aircraft route optimization when performing oil pollution monitoring of the sea aquatorium, Aviation, 21(2): 70-74. DOI: 10.3846/16487788.2017.1344139.
6. **Urbahs, A.; Zavtkevics, V.** 2017, Remote Piloted Aircraft Using for Sampling of Oil Spill. In: Transport Means 2017: Proceedings of the 21st International Scientific Conference, Lithuania, Kaunas, 20-22 September, 2017. Kaunas: Kaunas University of Tehnology, pp.489-492. ISSN 1822-296X.
7. **Goreļikovs, D.** 2015. Practical Realization of Unmanned Aerial Vehicle System for Collection of Data for Maritime Navigational Charts. In: Transport Means 2015: Proceedings of the 19th International Conference, Lithuania, Kaunas, 22-23 October, 2015. Kaunas: Technologija, 2015, pp.462-465. ISSN 1822-296X. e-ISSN 2351-7034
8. **Bellman, R.E.** 2003, Dynamic Programming, New York: Dover Publications, 366 p., ISBN: 0486428095, 9780486428093.
9. International Hydrographic Organization 2018, Publication S-66 – Edition 1.1.0, Facts about Electronic Charts and Carriage Requirements, Monaco.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Comparative Analysis of the Rolling Resistance Coefficients Depending on the Type of Surface – Experimental Research

P. Sawicki[1], K. J. Waluś[2], Ł. Warguła[3]

[1]*Poznań University of Technology, Piotrowo 3, 60-965 Poznań, Poland*
[2]*Poznań University of Technology, Piotrowo 3, 60-965 Poznań, Poland , E-mail: konrad.walus@put.poznan.pl*
[3]*Poznań University of Technology, Piotrowo 3, 60-965 Poznań, Poland, E-mail: lukasz.wargula@put.poznan.pl*

Abstract

Contemporarily there is a wide range of research methods that allow determining the rolling resistance coefficient thus enforcing to find an effective method of its estimation. Different obtained values of this coefficient depending on the assumed calculation method influence the quality and quantity assessment of cooperation processes between tire and surface. The article presents an experimental method of a coast-down test that enables to determine the rolling resistance coefficient. The value of the rolling resistance coefficient for the assumed road test method was determined in three ways. It enabled to compare chosen calculation models with values available in literature.
KEY WORDS: *rolling resistance coefficient, coast-down test, asphalt road, hexagonal concrete slabs, concrete slabs*

1. Introduction

Together with the development of technology over the last ten decades tire designers were aiming to construct tires with the lowest rolling resistance coefficient. The first wheel with a full tire was constructed at the end of 19th century and its rolling resistance coefficient was 30 kg/t [19]. The first pneumatic tires had a value of rolling resistance coefficient of 25 kg/t [19]. For the most modern tires the value is about 5 kg/t [19]. While the vehicle movement on a hardened surface the rolling resistance [6, 21]:

– increases with an increasing speed;
– increases with the tire deflection which is higher when the tire pressure is lower [16];
– increases while high torque transmission as the circumferential deformations of the tire increase. It concerns cars with high powered engines;
– decreases with tread -wear.

Table 1 presents average values of the rolling resistance coefficient for passenger vehicles and trucks depending on the kind of surface they move at.

Table 1

The rolling resistance coefficients sweet

Kind and state of the Road surface	**[4]**	**[18, 20]**	**[15, 23]**	**[9, 10]**	**[7]**	**[8]**	**[3, 12]**	**[13, 14, 22]**	
								Passenger vehicles	**Trucks**
Road with hardened surface – concrete, asphalt in good state	0,012 - 0,016, (author suggests to assume 0,002)	0,009 - 0,018			0,007-0,015	0,010-0,020	0,01-0,015		
Road with hardened surface – concrete, asphalt in worse state		0,020							
Smooth asphalt			0,01-0,012	0,01				0,012	0,010
Smooth concrete			0,012 - 0,015	0,011				0,014	0,012
Rough concrete				0,014				0,015	0,013
Road made of road metal in good state	0,023					0,023-0,025	0,015 - 0,05		

Kind and state of the Road surface	[4]	[18, 20]	[15, 23]	[9, 10]	[7]	[8]	[3, 12]	[13, 14, 22]	
								Passenger vehicles	Trucks
Road made of road metal covered by a thick layer of dust	0,028					0,028 - 0,030			
Road made of road metal- damaged, drove and muddy	0,035			0,035		0,035- 0,040			
Road made of road metal and tarred			0,016- 0,018						
Good country road - grater	0,035-0,05								
Country road in average state				0,80				0,05-0,14	
Country road in a very good state			0,03-0,06	0,045					
Muddy or sandy road	0,08-0,16					0,08-0,16			
Loose dry sand	0,15-0,3	0,015	0,15-0,3	0,15-0,30		0,15-0,3	0,15-0,3	0,15-0,3	
Road covered with gravel		0,030							
Cobblestone, paving block		0,030							
Road made of granite paving block			0,014- 0,016				0,015- 0,035		
Road made of granite paving block in a very good state				0,015				0,016	0,014
Cobbled road in a very good state								0,025	0,023
Road cobbled with field stones							0,035-0,06	0,04	0,035
Stone paving block in a poor state			0,03-0,033	0,033				0,033	0,03
Ground road - hard						0,035-0,50	0,03-0,1		
Ground road sandy and moisty		0,050- 0,150	0,08-0,15				0,08-0,15	0,08-0,15	
Snow								0,040-0,15	
Grass area								0,060-0,11	

The article presents the results of experimental research and the influence of assumed mathematical model of determining rolling resistance coefficient on its calculative value.

2. Rolling Resistances

In the equation of car movement the respective components of its movement resistance that have an impact on a moving vehicle are described by the following interdependence:

$$f_n = f_t + f_{aero} + f_w + f_u + f_b ,$$

where f_n - propulsion force; f_t - rolling resistance force; f_{aero} - aerodynamic resistance force; f_w - gravity force; f_u - vehicle construction resistance force; f_b - fictitious force.

It is assumed that the analysis of rolling resistance for a vehicle moving at a speed under 20 km/h other kinds of resistances can be omitted as they have a minor influence for the movement kinematics [1, 2]. Rolling resistance is

defined as the amount of energy a tire uses per a unit of a covered distance. The source of the rolling resistance is the viscoelastic properties of tires and surface deformation on which the car is moving [11]. The wheel while the car is stopped is loaded by Q_k force originating from the car's weight. The dispersion of pressure forces on the surface q_n together with the resultant of these forces Z_k (Fig. 1). When a vehicle moves, then the resultant of forces Z_k moves towards the driving direction by e value shown in Fig. 2.

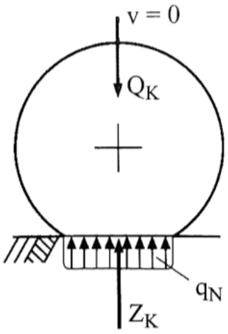


Fig. 1 Wheel pressure on the surface, when $v = 0$ [13]

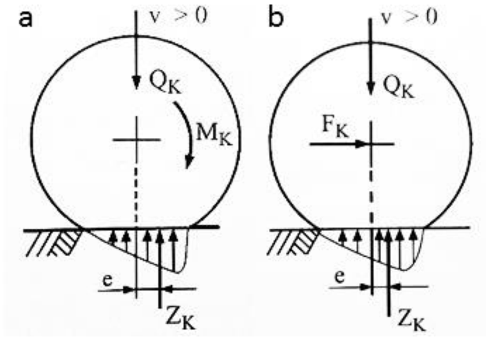


Fig. 2 Wheel pressure on the surface: a) propulsion wheel; b) rolling wheel $v > 0$ [13]

The rolling resistance force when wheels move without sliding is defined by the following equation:

$$F_t = f_t \cdot Q_k .$$

Being loaded Q_k rubbered wheel deflects what causes an increased area of contact between tires and surface. The main factors influencing the surface of contact area of tires with the roadbed are [1, 2]: car's weight, kind of surface, speed, kind of tires and their width, wheels alignment, tire pressure.

3. Coast-Down Test Method

Determining the rolling resistance coefficient may be done in many different ways. Additionally, within one method there are different ways, mathematical models that enable to calculate the value of rolling resistance coefficient. In this research the experimental tests were limited to the coast-down test method. The tests were made on three surfaces. The obtained results were processed in three ways which enabled to obtain the values of rolling resistance coefficient. Coast-down test method is relied upon a rule of momentum the research car/object to a given speed of 20 [km/h], and then putting a car on an idle gear in a specified place. It has been presented schematically in Fig. 3 [17].

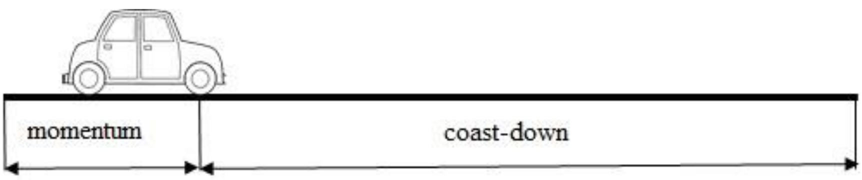


Fig. 3 Coast-down test method

The impeded car rolls thanks to the fictitious force and it speed decreases linearly due to rolling resistances until it is stopped. The distance covered at an idle gear must be measured as it necessary to determine the rolling resistance coefficient.

4. Road Tests

– Research object

In order to carry out the test the car Seat Leon was used. Before conducting the test car suspension geometry was set in order to minimize its negative influence on research results. The parameters of the researched car are shown in Table 2.

– Research place

The criteria for choosing research place was the angle of inclination to the horizontal of the road no more than $0{,}5^{\circ}$ and its rectilinearness. It enabled to limit significantly the interference from the driver to change the direction of the vehicle while coast-down tests For comparison purposes three types of surface were chosen that fulfilled these requirements, Fig. 4.

The tests were made on the same day in windless conditions in order to ensure the comparability of the atmospheric conditions. The atmospheric conditions were measured where the road tests took place; the measurements are shown in Table 3.

Table 2

Technical data of a research car

Weight	1188 kg	
Tires	Dunlop Sport Maxx RT 225/45/R17	
Tire pressure	2,3 bar	
Tread depth	~8mm	
Year of tire production	2016	
Milage	about 10 000 km	
Engine	1.4 TSI 110 kW	
Gear box	7-gear automatic	
Year of car production	2016	

Asphalt road

Hexagonal concrete slabs, so called Tryliński slabs

Concrete slabs

Fig. 4 The view of research surfaces

Table 3

The atmospheric conditions on the research day

Temperature outside	5,7°C
Atmospheric pressure	990,4 hPa
Humidity	91,5%
Dew point	4,5°C

5. Research Methodology

The rolling resistance coefficient f_t for the coast-down method can be determined in three ways [7].

The method with the use of a tape measure (method A)

There were 10 tests made on each of the surface. During the traverse test the following rules were applied:

– the marking of a starting point and the point of engaging idle gear;
– the car was accelerated to the speed of about 20 [km/h];
– after the car stopped itself, the position of the car was marked on the research surface;
– the covered road distances were measured.

When the coast-down started Total kinetic energy of the car is converted into work in order to overcome the rolling resistance. After transforming, the following equation was given which allows determining the rolling resistance coefficient:

$$f_t = \frac{v^2}{2 \cdot g \cdot S_t},$$

where v - speed of the car when coast-down started; g - standard gravity; S_t - coast-down distance.

The method with the use of measurement equipment (method B)

With the second method the researcher used the digitally collected data by a measurement device of Analog Devices company type ADIS 16385 placed on the roof of the car. On each of the surfaces, before starting the tests, the measurement device was calibrated.

Owning to the data collected from measurement device the characteristic of course of speed in time of the research car was obtained (Fig. 5). On the basis of this characteristic a part of coast-down of a research car was determined, omitting temporary states in order to avoid observational errors. It was assumed that the time that describes the coast-down of the car is the one during which the speed of the car lowers from 80 down to 10% of its maximum speed. As the speed during coast-down decreases linearly, this range was lineated and defined by the equation of a straight line. In this method the surface area is determined by the speed characteristics and on that basis the value of the rolling resistance coefficient is calculated.

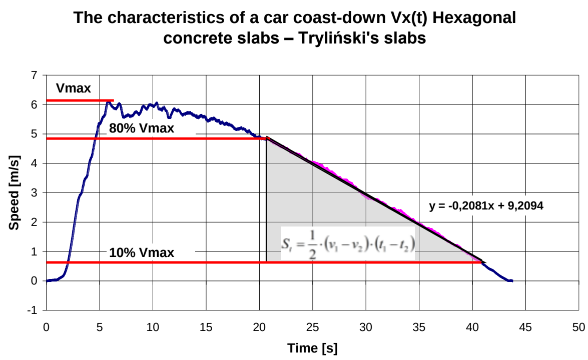


Fig. 5 A sample characteristic of the course of $V_x(t)$ for the coast-down test on a surface made of hexagonal concrete slabs with a determined surface area under the straight and the equation of a straight line

The method with the use of vehicle delay value (method C)

The third method to determine the value of the rolling resistance coefficient is based on the use of vehicle delay value. When the coast-down is started the value of the propulsion force equals zero. For the coast-down method in which car moves on an even, flat surface at a low speed it can be assumed that the aerodynamic, gravity and internal friction resistance is nearly zero [5]. It gives:

$$F_b = F_t,$$

where $F_b = m \cdot a \cdot \delta$; $F_t = m \cdot g \cdot f_t$.

Equating both sides the following equation for the rolling resistance coefficient was obtained:

$$f_t = \frac{a}{g} \cdot \delta,$$

where a - vehicle delay while coast-down [m/s^2]; g - standard gravity [m/s^2]; δ - reduced mass coefficient.

For each of the research test the vehicle delay was determined. The value of the delay was determined for every research trial. The value of the delay was taken from the equation of a straight line after linearization of vehicle's speed inclination. Determining the rolling resistance coefficient required calculating the reduced mass coefficient using the following equation:

$$\delta = 1 + \delta_2 ; \quad \delta_2 = \frac{4 \cdot I_k}{m \cdot r_d^2} ,$$

where I_k - wheel inertial moment [kgm²]; m - car's weight [kg]; r_d - dynamic wheel radius [m].

In order to calculate the value of reduced mass coefficient the value of wheel inertial moment, its dynamic wheel radius and the real car's weight was calculated. While the coast-down there was no interference into vehicle's direction, there was no braking or acceleration, that is why it was assumed that dynamic and rolling wheel radius equals the tangent radius and its value is 0,307 [m]. In order to determine the value of wheel inertial moment the calculation were simplified regarding wheel as a full cylinder where the mass distribution is even, then the value of I_k is 0,919 [kgm²]. Adding to the weight of the car driver's and passenger's weight the real weight of the car was obtained, which was 1390 [kg]. The determined parameters enabled to calculate the reduced mass coefficient, δ = 1,028. The determined values allow calculating the value of the rolling resistance coefficient.

6. Research Results

The road tests were carried out in accordance with the presented research methodology. In order to minimize the longitudinal inclination of the surface the trials were carried out in both directions, five drives each. The result of these tests and the values of the rolling resistance coefficient for three types of surfaces: asphalt road, road covered with concrete slabs and road covered with hexagonal concrete slabs (Tryliński's slabs) are presented in Tables 4 – 6.

Asphalt road

– → (method A)

The method with the use of tape measure – the coast-down distances were obtained for each of the trials. The results are presented in Table 4 together with the values of the rolling resistance coefficient.

Table 4

Test results on asphalt road for method A

Direction 1			Direction 2		
Trial nr	S_t [m]	f_t	Trail nr	S_t [m]	f_t
Coast-down	20,9	-	Coast-down	23,8	-
1.	170,8	0,0052	6.	45,9	0,0193
2.	177,2	0,0050	7.	51,8	0,0171
3.	170,2	0,0052	8.	50,7	0,0175
4.	167,3	0,0053	9.	45,4	0,0195
5.	165,1	0,0054	10.	39,2	0,0226
Average value f_t = 0,0122					

– → (method B)

The method with the use of measurement equipment ADIS 16385, in accordance with the methodology – the distance of the vehicle's coast-down was calculated choosing the time range for 80-10% *Vmax*, which allowed to determine the rolling resistance coefficient. The Speer, time, distance and rolling resistance coefficient values obtained with the use of method B for particular trials are shown in Table 5.

Table 5

Test results on asphalt road for method B

Trail nr	$v1$	$v2$	$t1$	$t2$	S_t	f_t
1.	3,69	0,45	30,66	81,05	81,62	0,0085
2.	3,75	0,47	40,30	78,63	62,83	0,0114
3.	3,75	0,47	40,30	78,63	62,83	0,0114
4.	3,61	0,46	17,79	80,32	98,42	0,0067
5.	3,50	0,44	16,61	78,19	94,35	0,0066
6.	3,98	0,49	10,25	28,61	31,98	0,0252
7.	3,76	0,47	12,99	30,62	28,98	0,0249
8.	3,67	0,46	13,13	30,37	27,71	0,0248
9.	3,41	0,43	12,03	29,03	25,39	0,0234
10.	3,96	0,50	10,19	29,29	33,06	0,0241
Average value f_t						0,0173

– → (method C)

Method C was used to calculate the values of the rolling resistance coefficient for all the drives of the research car and the results are presented in Table 6.

Table 6

Test results on asphalt road for method C

Trial nr	a	f_t
1.	0,0703	0,0074
2.	0,0889	0,0093
3.	0,0889	0,0093
4.	0,0498	0,0052
5.	0,0485	0,0051
6.	0,1918	0,0201
7.	0,1857	0,0195
8.	0,1856	0,0195
9.	0,1732	0,0182
10.	0,1785	0,0187
	Average value f_t	0,0137

The same experimental tests as for asphalt road were carried out on a road with concrete slab surface and hexagonal concrete slab (Tryliński's slabs) surface. The aggregated research results are presented in the chapter titled results analysis.

7. Results Analysis

Taking up the analysis the aggregation of results of average value of the rolling resistance coefficient was made as shown in Fig. 6.

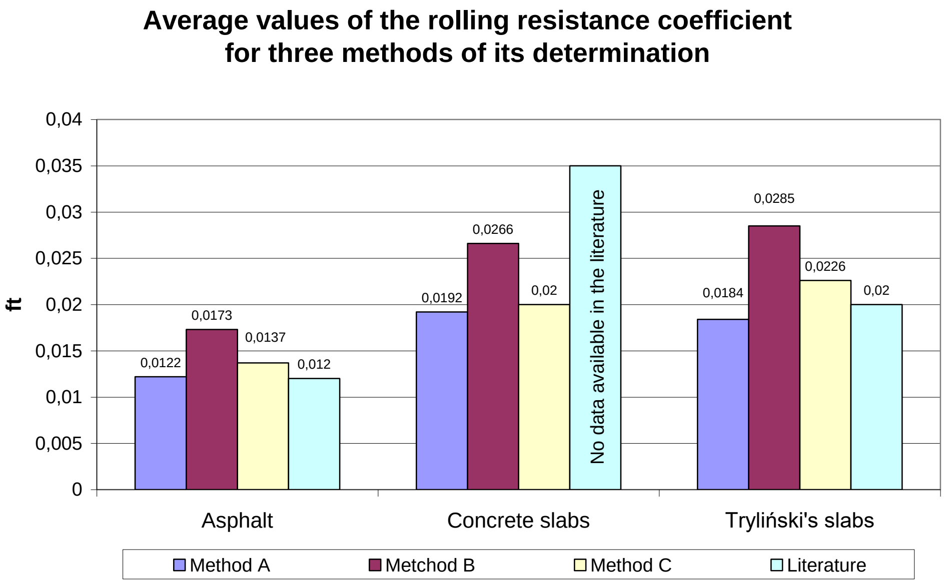


Fig. 6 The aggregation of results of average value of the rolling resistance coefficient

The disadvantage of method A was the lowest accuracy in determining the actual Speer of starting the coast-down. During the road tests the data was taken from the digital speedometer being a part of the car computer. The actual speed of starting the coast-down was unknown. What is more, it was assumed that the coast-down starts when the car's frontal axis crosses a point marked on the surface of the road. Despite all the effort rolling resistance coefficient to engage the idle gear exactly at the marked point in reality it could happen a bit earlier or later, which can be assumed as a potential observational error. Other calculating methods enable with quite a satisfying accuracy determine the parameters of the vehicle's movement and calculate the rolling resistance coefficient.

The research reveled that the lowest rolling resistance was on an asphalt road, then on Tryliński's slabs and the highest on concrete slabs which in accordance with the perceptions during road tests. Concrete slabs and their arrangement had a significant influence on the value of the rolling resistance coefficient. The faults between the slabs caused losses of energy and its dispersion in the vehicle's suspension system. This aspect can also be ob-served by the vehicle's speed characteristics which was not linear.

The course $V_x(t)$ for asphalt road was smooth for every trail and without any interference. On the basis of the above aggregation it can be stated that method A allowed to obtain on every surface the lowest value of the rolling resistance coefficient. Results from method B have the highest value of this coefficient. The greatest divergence

between the methods appeared while tests on concrete slabs. The results obtained with method B was 57% higher than with method A.

8. Summary

The road method of coast-down allowed to determine the value of the rolling resistance coefficient which is similar to one presented in literature. The coast-down method may be carried out in a traditional way by measuring the coast-down distance with a tape measure (calculations with method A) This method turned out to be the most effective and enabled to obtain the values of the rolling resistance coefficient as in literature. Other calculating methods cause an increase in the value of the rolling resistance coefficient but can be characterized by a higher precision of determining the kinematic parameters of movement of the research vehicle.

Assuming a specific calculation model determines the obtained values, whose divergence is noticeably visible. The most similar values are obtained using methods A and C. Method B of determining the surface area under the characteristics of vehicle speed changes caused obtaining higher values of the rolling resistance coefficient. It should be pointed out that this surface area was limited to the characteristics range of 80 to 10% of maximum speed which influenced the obtained results.

Choosing a research method and mathematical model it must be borne in mind that the obtained values of the rolling resistance coefficient depend on the assumed boundary and initial conditions of performed experimental tests and the observational errors influence the results significantly.

References

1. **Arczyński, S.** 1994. Mechanika ruchu samochodu. Wydawnictwa Naukowo-Techniczne.
2. **Arczyński S**.1976. Teoria ruchu samochodu. Wydawnictwa Politechniki Warszawskiej.
3. **Dębicki, M**. 1969. *Car theory. Drive theory* (original title in Polish: Teoria samochodu. Teoria napędu) WNT, Warszawa.
4. **Habich E**. Mechanika koła samochodu. http://bcpw.bg.pw.edu.pl/Content/1456/Techniczny_poradnik_samochodowy_cz1_str632_Mechanika_pojazdow.pdf
5. Instrukcja do ćwiczenia: Badania trakcyjne samochodu http://www.iepim.pr.radom.pl/dokumenty/BSiTR/Inst%202.pdf (data: 2016.09.19)
6. **Kulikowski, K.; Szpica, D**. 2014. Determination of directional stiffnesses of vehicles' tires under a static load operation, Eksploatacja i Niezawodność – Maintenance and Reliability 16(1): 66-72.
7. **Merkisz, J.; Pielecha, J.; Stojecki, A.; Jasiński, R.** 2015. The influence of terrain topography on vehicle energy intensity and engine operating conditions, Combustion Engines 162(3): 341-349, ISSN 2300-9896
8. **Minchejmer, A**. 1960. The theory of a moving car (original title in Polish: Teoria ruchu samochodu) Państwowe Wydawnictwo Naukowe, Warszawa.
9. **Mitschke, M**. 1977. Dynamika samochodu. Wydawnictwa Komunikacji i Łączności, Warszawa.
10. **Mitschke, M.** 1987. Car Dynamics. T. 1. Drive and braking (original title in Polish: Dynamika Samochodu. T. 1. Napęd i hamowanie) WKŁ, Warszawa.
11. Opona: opór toczenia a oszczędność paliwa. Clermont Ferrand: Societe de Technologie Michelin, 2003.
12. **Orzełowski, S.** 1996. Construction of chassis and car bodies (original title in Polish: Budowa podwozi i nadwozi samochodowych)., WSiP, Warszawa, ISBN 83-02-08785-8
13. **Prochowski**, **L.** 2008. Car vehicles. Movement mechanics (original title in Polish: Pojazdy samochodowe. Mechanika ruchu), WKŁ, Warszawa ISBN 978-83-206-1701-6
14. **Prochowski, L.; Unarski, J.; Wach, W.; Wicher, J.** 2008. Car vehicles. Basics of reconstruction of road accidents (original title in Polish: Pojazdy samochodowe. Podstawy rekonstrukcji wypadków drogowych) WKŁ, Warszawa ISBN 978-83-206-1688-0
15. **Siłka, W.** 2002. The theory of a moving car (original title in Polish: Teoria ruchu samochodu), Wydawnictwo Naukowo-Techniczne, Warszawa. ISBN 83-204-2748-7.
16. **Szczyglak, P.; Napiórkowski, J.; Rykowski, K.** 2016. The influence of the pressure in the tires on the vehicle's wheels rolling resistance (original title in Polish: Wpływ ciśnienia w ogumieniu na opory toczenia kół pojazdów) Autobusy. Technika, Eksploatacja, Systemy Transportowe 6: 1161-1165.
17. **Taryma, S.** 2007. Opór toczenia opon samochodowych. Wydawnictwa Politechniki Gdańskiej, Gdańsk.
18. **Wierciński, J.; Reza, A.** 2002. Road accidents. Vademecum of the court expert (original title in Polish: Wypadki drogowe. Vademecum biegłego sądowego. Wydawnictwo Instytutu Ekspertyz Sądowych, Kraków, ISBN 83-87425-65-6.
19. Artykuł http://autokult.pl/10711,podstawy-aerodynamiki-pojazdow-cz-1-co-wplywa-na-opor-aerodynamiczny (data: 2016.09.19)
20. Artykuł http://www.opony.com.pl/artykul/ranking-opon-badanie-oporu-toczenia-i-wytrzymalosci (data: 2016.09.19)
21. Artykuł http://nowegumy.pl/etykiety/
22. Artykuł http://super.moto.pl/temat/moto/opory+toczenia+gumy
23. http://www.technikajazdy.info/techniczne/wspolczynnik-oporu-powietrza/

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Concept of Wind Speed and Direction Measurement by COTS Multicopter

R. Bystřický[1], M. Dub[2]

[1]*University of defence in Brno, Kounicova 65, 66210 Brno, Czech Republic, E-mail: radek.bystricky@unob.cz*
[2]*University of defence in Brno, Kounicova 65, 66210 Brno, Czech Republic, E-mail: michal.dub@unob.cz*

Abstract

Weather forecast is one of the most important issues in aviation safety. The paper deals with possibilities of meteorological data measurement in the ground layers of the atmosphere that is cheap and can be used repeatedly unlike the standard measurements using meteorological balloon. Nowadays small meteorological balloons are launched according to a fixed schedule all around the world. The balloon carries small measurement device and GPS receiver so balloon position and drifting speed can be measured. Alternative methods are searched for today and one of the popular methods is to use UAV. There are several possibilities to measure the parameters of the wind by UAVs but all of them except one require adding more equipment resulting in carrying more weight and consuming more electric energy. The paper introduces all necessary mathematical apparatus for wind speed and direction measured by the multi-copter using only onboard instrumentation. Experimental results of the drone hovering and climbing in moderate and fresh breeze are presented including issues of determining the multicopter reference area and the drag coefficient.

KEY WORDS: *UAV, Wind measurement, Euler angles*

1. Introduction

Basic meteorological measurements have been carried out for a number of years. In case of the Czech Republic, this history dates back to 1946. Since 1957, the probes have been released every day at 0 h, 6 h, 12 h and 18 h according to UTC time standard. This status lasted until 2013 when the 18 hour was canceled, mainly for financial reasons [5]. The probe itself consists of a hydrogen filled meteorological balloon (about 1 m in diameter) and a meteorological probe is tied up to the balloon by an approximately 10-20 m long rope, see Fig. 1. The measurement itself consists of sensing the air temperature, humidity, pressure, and GPS position of the probe (Fig. 2) determines the direction and wind speed at individual heights [6].

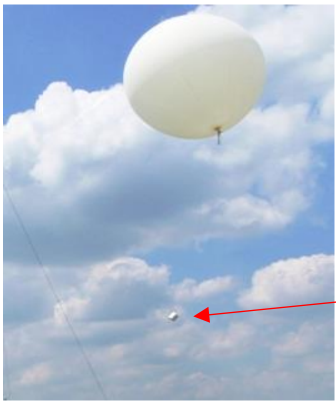


Fig. 1 Meteorological balloon probe

Fig. 2 Vaisala probe RS92-SGP

The huge drawback of this method is the fact that once launched the probe is not reusable for further measurements due to the fact that the balloon bursts once it reached a height of about 30-35 km. The probe then freefalls to the ground resulting in irreversible damage. The price of the probe is unfortunately difficult to ascertain, but it can be estimated to be about 200 USD per piece.

One of the possible alternative ways is to replace the balloon itself with another carrier. If we for a moment ignore nowadays legislative rules, it is quite easy to imagine an unmanned UAV that would meet the basic parameters of availability and endurance and would be able to safely carry the measuring probe back to the ground [3].

Several articles devoted to the wind measurement can be found most of the time however; uses classical airplane. In our case multirotor drone has been selected. For our purposes, the lowest 2 km are sufficient and manual control is therefore assumed. Manual control means that the drone must perform only pure vertical ascend and descend otherwise the drone would drift too far away due to the wind. However, a drone flying pure vertical profile will lose the ability to measure the wind parameters derived from the GPS signal and another method is needed.

There are several possibilities to measure the parameters of the wind by UAVs but all of them except one require

adding more equipment resulting in carrying more weight and consuming more electric energy [4]. We propose to use only standard onboard instrumentation including GPS receiver and flight controller of small COTS unmanned multi-copter. The main idea of this paper is therefore to describe this possibility to measure wind speed and direction.

2. Mathematical Background

Drone can easily maintain the horizontal position and climb at a constant speed. The direction of wind can be calculated from UAV tilt because wind is pushing the hovering UAV from this position and GPS onboard system corrects this drift by tilting the UAV against the wind. The speed of wind can be then calculated from UAV thrust lateral component determined by UAV tilt.

Let's assume that the drone hovers in the steady stream of wind and the flight control system is keeping its horizontal position fixed. As the wind pushes the drone out of its fixed position the flight controller react by tilting the drone opposite to the wind in order to keep its desired position. As the wind grows stronger, the tilt of the drone grows as well. The lateral component of the thrust (T) must balance the force that wind exerts on the drone. The vertical component of the thrust must accordingly balance the weight of the drone. The forces acting on the drone can be therefore drawn according to the Fig. 3.

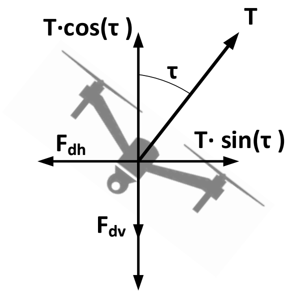


Fig. 3 Forces acting on the drone

The situation depicted on the Fig. 3 can be mathematically rewritten as follows:

$$\left.\begin{aligned} &F_{dh} = T \cdot \sin(\tau) \Rightarrow \frac{1}{2}\rho \cdot u^2 \cdot c_d \cdot A = \frac{m \cdot g}{\cos(\tau)} \cdot \sin(\tau) \Rightarrow u = \sqrt{\frac{2 \cdot m \cdot g \cdot \tan(\tau)}{\rho \cdot c_d \cdot A}}; \\ &F_{dv} = T \cdot \cos(\tau) \Rightarrow T = \frac{m \cdot g}{\cos(\tau)}, \end{aligned}\right\} \tag{1}$$

where ρ - is the mass density of the air; u - is the flow speed of the object relative to the fluid (wind speed); c_d - drag coefficient; A -is the reference area; m - masse of the drone; g - gravitational acceleration; τ - total tilt angle of the drone; T - thrust generated by the propellers.

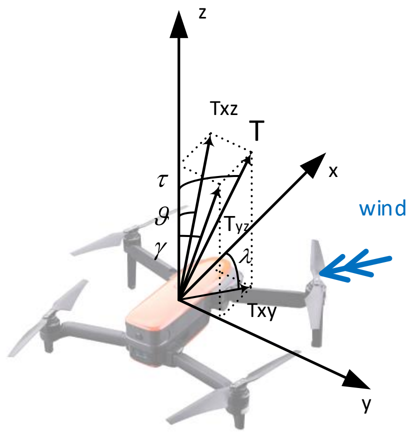


Fig. 4 Euler angles in Earths frame of reference

To calculate the total angle of tilt τ we must correctly combine both Euler angles roll γ and pitch ϑ. Together with the third Euler angle ψ representing the yaw of the drone, the direction of the wind can be estimated as well. The Fig. 4

shows the situation for forward and right tilt. Total tilt angle τ is angle between unit vector normal to the XY-plane and the cross product of the two Euler angles roll γ and pitch ϑ:

$$\vec{n}_{XY} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}; \quad \vec{e}_{\gamma} = \begin{pmatrix} 0 \\ \cos(\gamma) \\ \sin(\gamma) \end{pmatrix}; \quad \vec{e}_{\vartheta} = \begin{pmatrix} \cos(\vartheta) \\ 0 \\ -\sin(\vartheta) \end{pmatrix}; \quad \vec{e}_{\gamma} \times \vec{e}_{\vartheta} = \begin{pmatrix} -\cos(\gamma)\sin(\vartheta) \\ \sin(\gamma)\cos(\vartheta) \\ -\cos(\gamma)\cos(\vartheta) \end{pmatrix}. \tag{2}$$

Total tilt angle τ can be calculated from scalar triple product of these vectors as follows:

$$\vec{n}_{XY} \cdot \left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right) = \left|\vec{n}_{XY}\right| \cdot \left|\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right| \cdot \cos(\tau)\,; \tag{3}$$

$$\tau = \cos^{-1}\left(\frac{\vec{n}_{XY} \cdot \left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)}{\left|\vec{n}_{XY}\right| \cdot \left|\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right|}\right). \tag{4}$$

The final formula for tilt angle τ is then:

$$\tau = \cos^{-1}\left(\frac{-\cos(\gamma)\cos(\vartheta)}{\sqrt{\cos^2(\gamma)\sin^2(\vartheta) + \sin^2(\gamma)\cos^2(\vartheta) + \cos^2(\gamma)\cos^2(\vartheta)}}\right). \tag{5}$$

The projection of the vector $\left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)$ on the XY-plane (i.e. in X-axis and Y-axis) is needed to determine wind direction ψ'. The decision algorithm is implemented because arctangent function is restricted to its principal branch $\left\langle -\frac{\pi}{2}, \frac{\pi}{2} \right\rangle$.

$$\psi' = \left\{ \begin{matrix} 90 - \tan^{-1}\left(\dfrac{\left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_Y}{\left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_X}\right), & if \left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_Y \rangle 0 \\ 270 - \tan^{-1}\left(\dfrac{\left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_Y}{\left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_X}\right), & if \left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_Y \rangle 0 \end{matrix} \right\}. \tag{6}$$

The final formula for the wind direction ψ' is then:

$$\psi' = \left\{ \begin{matrix} 90 - \tan^{-1}\left(\dfrac{\sin(\gamma)\cos(\vartheta)}{-\cos(\gamma)\sin(\vartheta)}\right), & if \left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_Y \rangle 0 \\ 270 - \tan^{-1}\left(\dfrac{\sin(\gamma)\cos(\vartheta)}{-\cos(\gamma)\sin(\vartheta)}\right), & if \left(\vec{e}_{\gamma} \times \vec{e}_{\vartheta}\right)_Y \rangle 0 \end{matrix} \right\}. \tag{7}$$

However, the measurement of wind profiles in turbulent environments (for instance behind and between large wind turbines) is more interesting. Under this condition, the steady state assumption is no longer valid and dynamic effects should be considered. The inertia of the vehicle, together with its linear and rotational acceleration and velocity has to play an important role in the new wind vector estimation [1].

3. Testing Apparatus

In order to measure the real wind speed a drone capable of carrying significant load and having reasonable flight time was bought. This drone is capable of carrying parachute, Vaisala probe, our own meteorological measurement unit and still stays in the air for more than 20 minutes. At present, the drone is fitted with pressure and humidity sensor BME280 by Bosch, which communicates via I2C interface. It measures humidity from 0% to 100% and pressure from 300 hPa to 1100 hPa with definition 0.08% for humidity and 0.18Pa for pressure. The precision in the case of humidity is ±3% and ±1Pa for the pressure. Additionally, it comprises a platinum temperature sensor 701-101BAA-B00 by Honeywell with a measuring range of -70°C to 500°C and definition that thanks to the used processing chain amounts to 0.01°C. Occasionally the drone carries the Vaisala probe as shown in the Fig. 5.

The flight controller is capable to record big number of internal parameters, e.g. Euler angles, GPS position, barometric speed and altitude, etc. All parameters that are measured are timestamped with us precision. This allows all sorts of post processing, in our case to calculate the wind parameters.

Fig. 5 Drone created by the Robodrone company, modified to perform meteorological measurements [7]

To achieve flight levels up to desired height the drone passed National Aviation Authority check and we received authorization to fly up to 5000 ft AMSL. This permission also requires us to request temporary restricted flying zone with appropriate height and radius. The request for the restricted zone takes some time to arrange and it is therefore not as easy to perform one flight as one may think.

4. Initial Results

To verify that the mathematical apparatus created to calculate the wind works accordingly, two parameters are required. It is the product of drag coefficient and the reference area $c_d{\cdot}A_{xy}$. The drone has been taken to the field near the meteorological pole in Košetice and flight test has been conducted. The flight was performed in a particular altitude that correspond to the location of the wind speed and direction measurement devices. These measurements were used to compare calculated value of the $c_d{\cdot}A_{xy}$ product based on the known wind speed. One of the inconveniences of the meteorological probe is that it measures only mean values over one minute period. The flight time in the proximity of the sensor must be therefore sufficiently long in order to compare data with sufficient certainty.

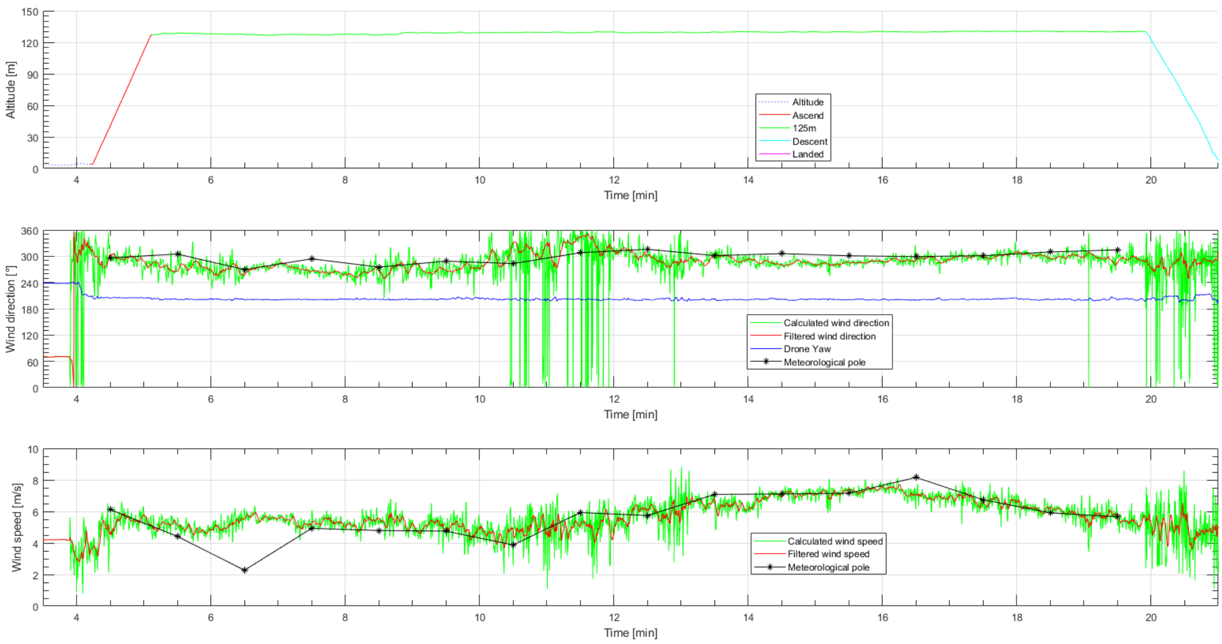


Fig. 6 Flight test to determine the $c_d{\cdot}A_{xy}$ product

Since we cannot predict the wind situation at the site several weeks ahead we had to performed several flights in different meteorological conditions. For the above-described experiment, only those with rather steady wind flow were used. The Fig. 6 shows one of the flight where the wind direction was relatively stable and the speed of the wind was changing only slowly.

Based on those experiments the value of the drag ($c_d{\cdot}A_{xy}$) has been set, although in all cases the wind speed stayed in relatively small window varying only from 4-7 m/s. We need to measure the value of the drag over the whole 0-15 m/s range as the variation of this value is expected to be dependent on the total angle of the tilt.

5. Advanced Results

Once the value of the drag is known we can created another experiment. This time we can fly in parallel with the real meteorological probe. This way our measured data should correspond to those measured by professional probe. This measurement took place in Prostějov where one meteorological station, releasing balloon twice a day, is located. This time we had not only to prepared the drone and the measurement, but also request temporary restricted flying zone to assure that the drone can con cause any harm to the real world air traffic as a flight to the height of 5000 ft was expected.

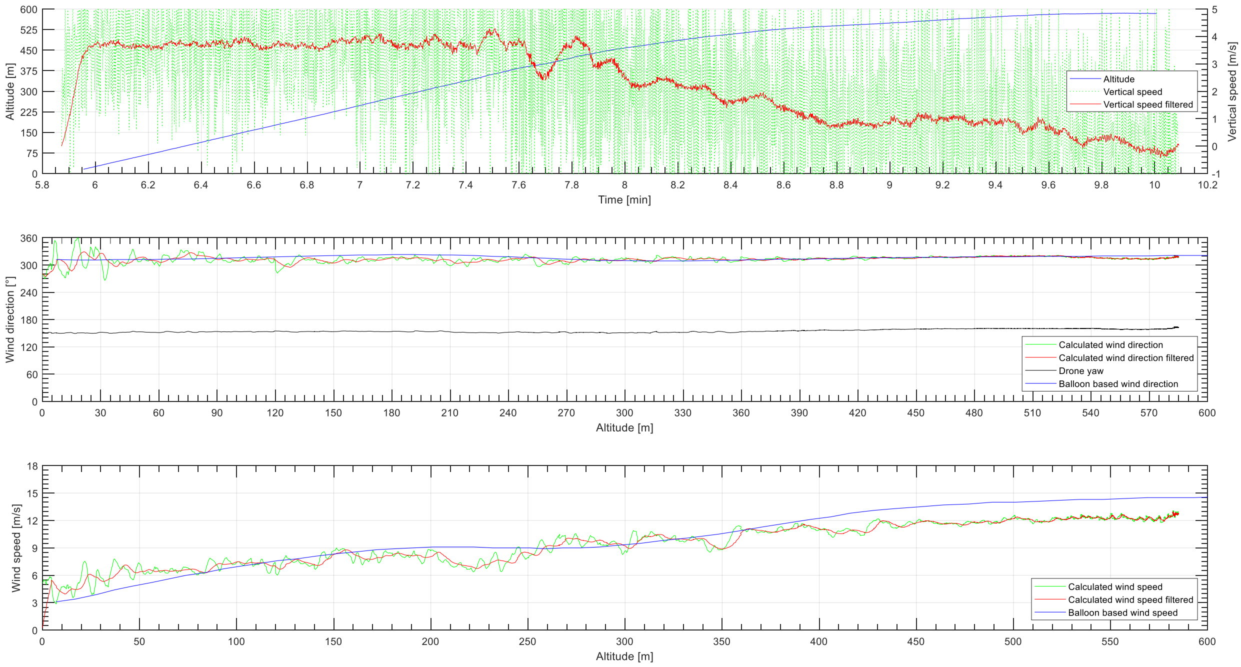


Fig. 7 Comparative flight with the meteorological balloon

The Fig. 7 shows this recent flight. However, the weather that particular day was exceeding some limits of the drone. The temperature was just above 3°C, it rained all day and therefore frost was expected to form on the propellers. It was decided to fly only to the height of 3000 ft to avoid this hazardous situation.

What we did not know was the fact that at the desired altitude of 3000 ft the wind was exceeding the limitation of the drone. We learned that fact during the flight. The drone, once reached its limits, slowed the ascend and later completely refused climbing as you can see from the figure 7.

The direction of the wind is followed perfectly. It is also visible that higher the wind speed is the better the wind orientation is calculated. The total angle of tilt is more pronounced and therefore wind perturbations do not affect the calculations as much as if the wind is slow. It must be also noted that while the drone measures data 10 times per second, the balloon gives data only once every 2 seconds and its internal algorithm is unknown. It is therefore hard to approximate the filtering used inside the probe to obtain comparable data. The much higher sampling frequency results in a much more dynamic behavior.

The wind turbulent behavior is significantly affecting the estimated value of the wind speed at the low altitude. At higher altitude where the wind is not as turbulent is the speed calculated better. At the speed about 10 m/s the tilt of the drone is so significant that the estimated value of the drag ($c_d \cdot A_{xy}$) is no longer valid. Since the limitation of our drone is 15 m/s it is clear that measurements in aerodynamic tunnel must be made in order to properly determine the drag. More over the drone is not completely symmetrical and therefore for different value of the yaw one can expect different value of the drag as well. In this case, the angle λ was 100° respectively 160° and therefore the difference between the both cases is approximately 60°. Such difference is rather significant.

Another thing that must be mentioned is the fact that the balloon climbs at a rate of approximately 7-8 m/s and the drone with only 4-5 m/s depending on the wind strength and stability and that the balloon drifts away from the place where the drone climbs. It means that the wind situation may be different. Finally, without the proper measurement from the wind tunnel, it is almost impossible to calculate the vertical component of the drag caused by the climbing movement and it was for this second experiment consciously ignored.

6. Conclusions

The paper showed that wind direction and wind speed can be measured using only standard on-board instrumentation including GPS receiver and flight controller. Initial field measurements clearly show that the direction can be estimated with precision comparable to classical meteorological methods. The wind speed, assuming that the drag

coefficient is known with sufficient precision, can be also estimated keeping nearly the same precision.

It has been also depicted that using the drag valid for one wind speed and orientation cannot be used for all cases. The aero dynamical coefficients must be measured for all speeds and angles of tilt, which can represent substantial amount of work. This work however must be done in order to estimate the wind parameters accurately. Measurements in aerodynamic tunnel are pending.

Acknowledgement

The work presented in this article has been supported by the Ministry of Defence of the Czech Republic (UoD development program "Research of sensor and control systems to achieve battlefield information superiority").

References

1. **Moyano, C.J.** 2013. Quadrotor UAV for wind profile characterization. Master's Thesis. Available from: https://e-archivo.uc3m.es/handle/10016/18105
2. **Condomines, J.; Bronz, M.; Hattenberger, G.; Erdelyi, J.** 2015. Experimental Wind Field Estimation and Aircraft Identification. Available from: https://www.researchgate.net/publication/282003424_Experimental_Wind_Field_Estimation_and_Aircraft_Identification
3. **Villa, T.F.; Gonzalez, F.; Miljievic, B.; Ristovski, Z.D.; Morawska, L.** 2016. An overview of small unmanned aerial vehicles for air quality measurements: Present applications and future prospectives. Sensors, 16(7), 1072.
4. **Giebel, G.; Paulsen, U.S.; Bange, J.; la Cour-Harbo, A.; Reuder, J.; Mayer, S.; Mølgaard, J.** 2012. Autonomous Aerial Sensors for Wind Power Meteorology - A Pre-Project. Available from: http://orbit.dtu.dk/files/7726678/ris_r_1798.pdf
5. Czech hydrometeorological institute – aerological department. [online cit.: 2018-06-30]. Available from: http://portal.chmi.cz/o-nas/organizacni-struktura/usek-meteorologie-a-klimatologie/odbor-distancnich-mereni-a-informaci/oddeleni-aerologicke/odborna-cinnost
6. Rádiosonda RS92-AGP, SGP, D. [online cit.: 2018-06-30]. Available from: http://www.radiosonda.sk/?page_id=262
7. Robodrone – Superhornet. [online cit.: 2018-06-30]. Available from: https://www.robodrone.com/en/superhornet

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Software Tool for Railway Traffic Modelling Under Conditions of Limited Permeability

Z. Dvořák[1], B. Leitner[2]

[1]*University of Žilina, Faculty of Security Engineering, Department of Technical Sciences and Informatics, ul 1. mája 32, 010 26 Žilina, Slovak Republic, E-mail: zdenek.dvorak@fbi.uniza.sk*
[2]*University of Žilina, Faculty of Security Engineering, Department of Technical Sciences and Informatics, ul 1. mája 32, 010 26 Žilina, Slovak Republic, E-mail: bohus.leitner@fbi.uniza.sk*

Abstract

Existence of crisis situation and crisis event in railway transport and reduction of its consequences can be influenced up to certain point by applying technological procedures and proper preparations. Decision process is represented by railway transport on route sectors and its organization in case of violation by diverse hazards – stochastic impacts. Number, size and impacts of crisis situations which are occurring in the society are still growing. Their occurrence is caused by natural factors and anthropogenic factors. One of the limiting factors in crisis manager activity or dispatching site is to obtain sufficient amount of exact and fast information and sufficient computer support to decision process. The paper describes issues connected to the theoretical assumptions for operational planning in rail transport. Software tool ASTRA+ can be used to provide above mentioned missing information support. Software tool was designed by University of Žilina for modelling and operational planning of railway traffic, especially in crisis situations.
KEYWORDS: *railway traffic, limited permeability, modelling of rail traffic, software tool*

1. Introduction

Occurrence of crisis situation in rail transport and reduction of its consequences can be influenced up to certain point by applying technological procedures and proper preparations. This is valid also in railway transport and in its technological processes. Decision process is represented by railway transport on route sectors and its organisation in case of violation by diverse haphazard – stochastic impacts.

Number, size and impacts of crisis situations which are occurring in the society are still growing. Their occurrence is caused by natural factors and anthropogenic factors. Very serious are human activities like environmental pollution or international terrorism, which play the most important role. These impacts take place in railway transport and they bring need to develop preventive measures for solution of arisen crisis situation and for elimination of their impacts. One of the limiting factors in work of crisis manager or dispatching site is to obtain sufficient amount of exact and fast information and sufficient computer support to decision process. Software tool ASTRA+ can be used to provide above mentioned missing information support.

2. Theoretical and Methodological Aspects of the Problem Solution

Now, the rail transport is crucial amongst all used transport means. Comparing to other transport means in cases of crisis situations and their solutions, rail transport has many advantages:

- it has high transport capacity;
- it is highly reliable; it does not depend on day time or weather;
- it is suitable for public transport and material transport on medium and large distances;
- it reaches high sector (or maximal) speed.

On the other hand, it has also some disadvantages:

- Transport speed is relatively low (from the moment of loading of goods to the moment of unloading),
- In case of transport infrastructure damage its renewal requires lot of time and lot of money,
- It requires especially trained employees,
- It requires powerful machines for removal of consequences of accident [17].

The experience shows that in cases of crisis situations of wide ranges, when the road transport was passed away or its capacity was low, the railways were working without limits. Especially in cases of huge evacuations the rail transport was the most important transport mean.

Crisis and extraordinary situations in transport infrastructure can cause violation or abruption of transport. In cases of transport infrastructure violation, the transport can be started immediately. In case of transport abruption, the renewal has to be proceeded to provide basic transport capacity. In both cases the transport could be done in limited range according to not usual organisation [5].

In present time there is a plan to prepare a number of actions focused on transport route renewal which should

help in removing of negative aspects in railway transport. Unfortunately, there exists no unique method, aimed on providing required transport capacity by effective way in conditions of limited transport capacity, which could create functional technology for railway transport [2.]

Due to mentioned facts and issues the project realised following actions:

- Elaboration and application of modern management methods on chosen problems.
- Theoretical investigation in the area of interest based on testing by the computer program ASTRA as well as it's practical usage in cases of crisis situations.
- Defining of management algorithms for managing of railway transport in limited conditions.
- Testing of possible evaluations of transport situation on route sector or whole route.
- Creating of general theory as a base for future research and solution finding for transport technology problems in crisis situations.
- Creating of the crisis train diagram in railway transport.

Above mentioned procedure was a base for creation of algorithms and models. Using created algorithms and models we created individual sub-programs what led to creation of program product, which is dedicated to operational planning in railway transport [3, 4].

Our institution is working on issues of modelling in railway transport in a long-term horizon. In past we were owner of sufficient programming environment as well as high performance computers. After year 2000 we started with development of our own theoretical models, which were based on huge statistical investigation. We investigated in detail what are the connections and dependences of travelling time on twenty track sectors. We processed more than 30 thousands of data sets about real time for individual trains to pass the route [4, 13, 18].

We designed our own algorithms based on those findings. Mathematical support was based on many well-known mathematical and statistical methods. First real results show the impeachment of well-known division of probabilities. We were forced to find different variations of probabilities. The results of our research were applied into created program product ASTRA+ for traffic modelling on the railway section.

3. Used Mathematical Apparatus

Research in this field is connected to many problems. One of them was that it is not possible to apply chosen theory on mathematical models for all situations. Therefore we changed applied theoretical apparatus. We also changed methodology of calculation for simulations and we modified designed program. We designed ASTRA+, which is able to model and simulate problems also on one track routes [7].

The railway transport in route sectors is possible to understand as bulk service system and it considers railway route as a service line. It is a system, which is also well-known as M/M/1, where there are no limits in requirements, stations of services are limited (in our case it is one service station) and waiting for service requirements. The simulation of traffic in railway route sectors depends on three parameters: Time interval of train entrance to the route sector, Time of route sector occupancy, Number of route and station tracks, on which the traffic will be done and can be possibly used for waiting of trains [12].

During evaluation of transport capacity of route sector we did not consider only route sector between two neighbouring train stations, but we evaluated route sectors between so called train-created (arrange, configure, create) stations. Such sectors are for instance relay Žilina (Station A) – Vrútky (Station B) – Poprad (Station C) – Košice (Station D). Railway route sector can consist from different number of partial route sectors (Fig. 1).

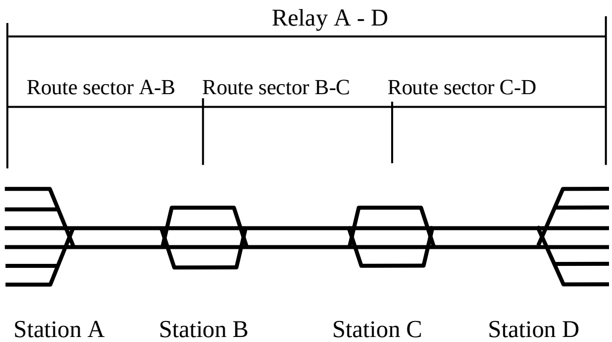


Fig. 1 Graphical description of train-created stations

Significant part of crisis situations leads into lowering of number of route tracks. If there is only one track available, instead of two route tracks it changes technology of railway transport rapidly.

Incoming flow of requirements – trains are originating in train generating stations on direction tracks. Generated trains are waiting for departure in outgoing set of tracks where they can create queue. The tracks in selected train stations are used for train journey, but they can be also used for train stopping while waiting. Due to the limitation of track number there are also limits for queue – number of trains waiting [11, 12, 14].

It is not possible to prepare the train transport diagram with consideration of floating displayed actions (train

journey, station intervals, train and station measures and action etc.). Time needed for these actions has to be constant. Duration of train passing the same route sector has to be planned as fixed, despite the fact it is not like this. The fact is that the program ASTRA+ does not offer constant time duration of activities, so it will be essential to add this function. The main problem is which value should be used. Erlang's distribution is sidelong to the right [10].

$$f(x) = \frac{b^a (y - y_0)^{a-1}}{(a-1)!} exp\left[-b(y - y_0)\right]; \tag{1}$$

$$F_x = \int_{y_0}^{y} \frac{b^a (y - y_0)^{a-1}}{(a-1)!} exp\left[-b(y - y_0)\right] dy. \tag{2}$$

After announcing of one of the crisis states, the Railways of Slovak Republic (next ZSR) can organize railway transport according to "crisis train diagram of railway transport". This train diagram is based on "list of passenger trains for crisis situation period". Example case of such situation is shown on Fig. 2 [13, 14].

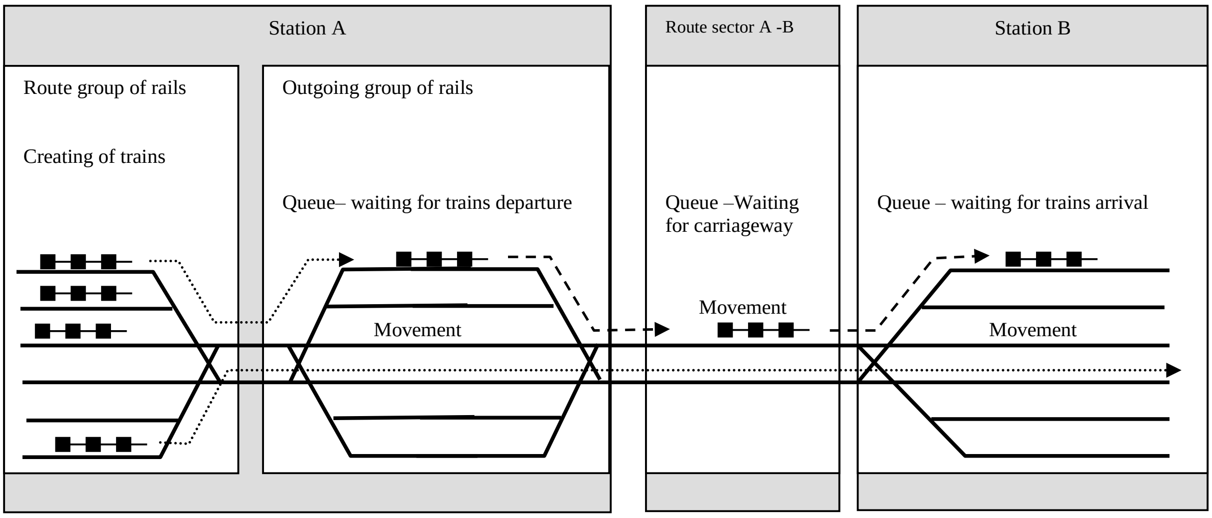


Fig. 2 Graphical description of train-created stations

The dilemma was whether we should use average of generated values or median of maximal and minimal generated value. Decision variable for simulations in railway transport is the time of occupying of route sector:

$$t_{obs} = t_j + \tau_n, \tag{3}$$

where interval τ_{nj} is generally considered to be random variable. Therefore we can consider travelling time t_j also to be random variable. The best description of travelling time is by Erlang's distribution of random variable, which uses two parameters a and b. Parameter a is in all cases constant a = 16. Parameter b is dependent on median of travelling time $t_{j,p}$ and it is calculated from ratio $b = a / t_{j,p}$. Above mentioned solutions are valid only for two track routes. The solution in their case is usually quite simple.

4. Software Support for Railway Traffic Modelling Under Conditions of Limited Permeability in Rail Section

In Slovak Republic the total constructed length of railway routes is 3 658 km. Single track routes has length of 2 640km, which 72% of total route length. Double and more tracked routes have length 1019 km, which is 28% of total route length. In railway network of ZSR there are 8 767 rail-switches, 2 283 railway bridges and 76 railway tunnels [16].

According to these statistics we can assume that the most probable decrease in transport capacity is in case of single track route. Solution of such problem is much more problematic task than it was in previous case. The most crucial issue connected to this task is the fact that if the transport is organised on single track route, trains are entering route sector from both sides. Therefore it is needed to evaluate train's position and based on this to recalculate their passing in railway stations. Condition of determined inputs of trains is in this case much more serious, because it is not possible to overcharge route sector. Trains can enter only if the situation at least theoretically enables their continuous ride. These situations will be always managed by operators and therefore we cannot define it as stochastic inputs of trains. According to change in theoretical apparatus was program ASTRA redesigned into ASTRA +, which is able to model and simulate railway traffic on double track routes, on single track routes including the cascade traffic on single track routes. Solution of this kind of problem was solved in program product ASTRA+ (Fig. 3).

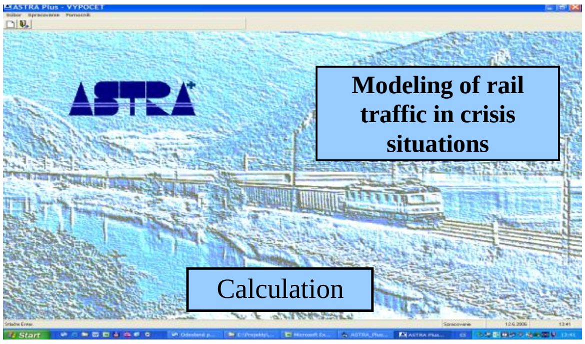


Fig. 3 The splash screen of software ASTRA +

4.1. Input and Verification of Data

The practical part of solution was realised for several years. The matter of program product is based on detailed database data about stations, tracks, railway bridges and tunnels.

Participants on this project were working with original technical details gained in previous projects. Based on digitalisation in creating train transport diagram and onward filling in of databases about particular railway objects by data from modern measuring devices, present data metafile was imported directly from railway infrastructure provider. Basic algorithm of program structure is shown on Fig. 4.

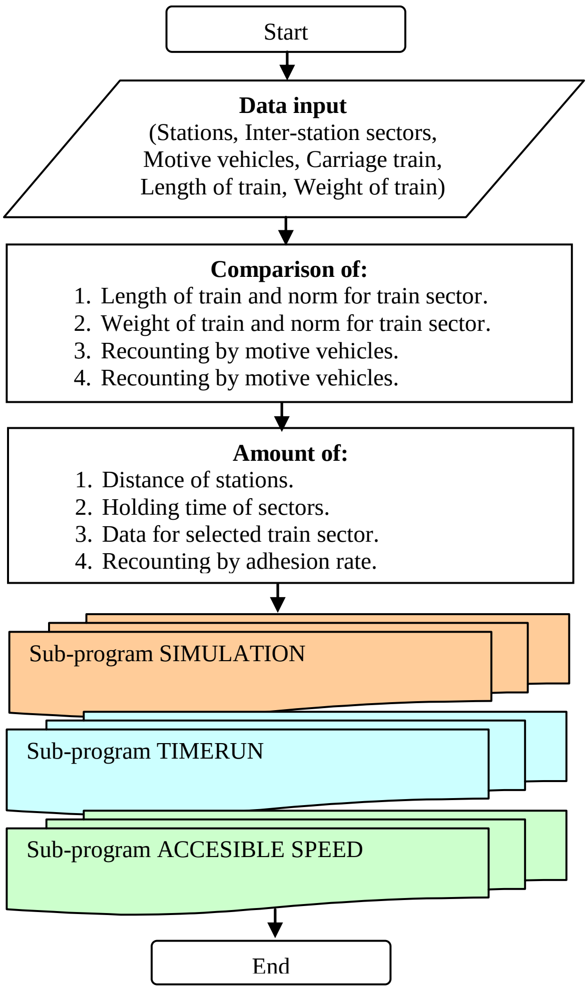


Fig. 4 Scheme of data input - software ASTRA

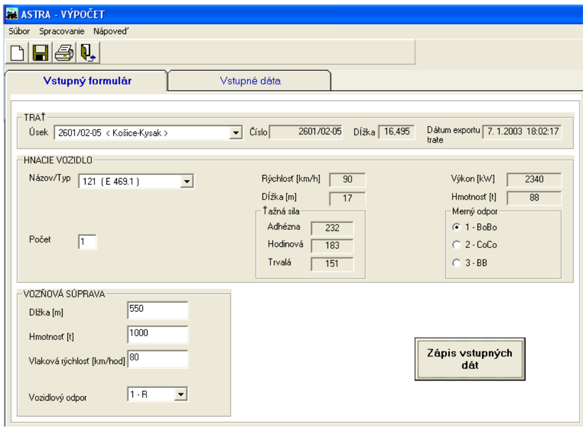


Fig. 5 Window for data input

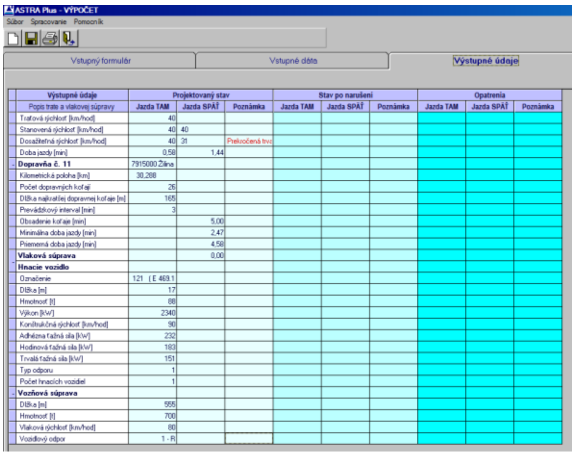


Fig. 6 Window showing real data in database

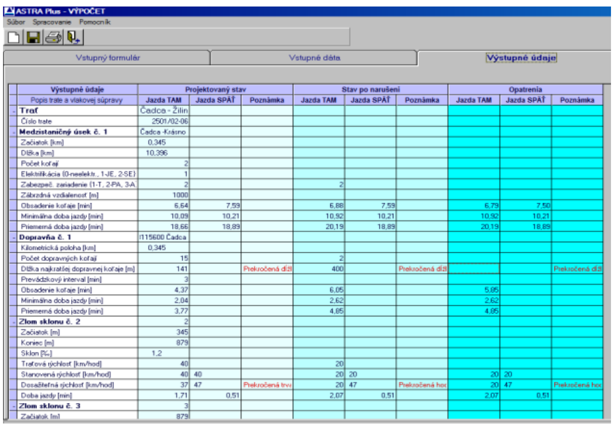


Fig. 7 Window output data

The input of data is preceded through the roll bars (Fig. 5). Roll bar ROUTE (in Slovak TRAT) – gives a possibility to choose from any railway route that operate by Railways of the Slovak Republic (next ZSR). The roll bar motive vehicle offers all possible vehicles for selected route.

After choosing the route and selection of database fields, real data for route segment are loaded into window for data input. It is possible to change some of the data in mentioned detailed data fields. This can lead to change in transport capacity. Mentioned changes will be shown in note column and will be highlighted in red (Fig. 6).

The work and proceeding of real data was very important part of the project. Problematic objects were shown in red colour in output window (Fig. 7). For everyday work in transport railway companies it is important to bring new technical or technological solutions with paying attention to these objects [7-9].

4.2. Process of Computer Simulation

Graphical visualisation is based on displaying of computer simulation calculated values in form of agreed signs in real time according to selected time scale. The stations of simulation model are displayed by graphical signs on monitor in dependence to their position on selected scale. The trains are displayed by black spots according to time and location. Displaying consists from:

- Static objects as stations, tracks, station rails, security systems characterised by their location and distance in kilometres, state and number of tracks.
- Dynamical objects such as train sets which are characterised by location and speed.

Displaying is proceeded in:

- Moments of timer violation (violation of timer is done in given time intervals, which can be changed during simulation).
- Moment, when new requirement (train) enters the simulation model.

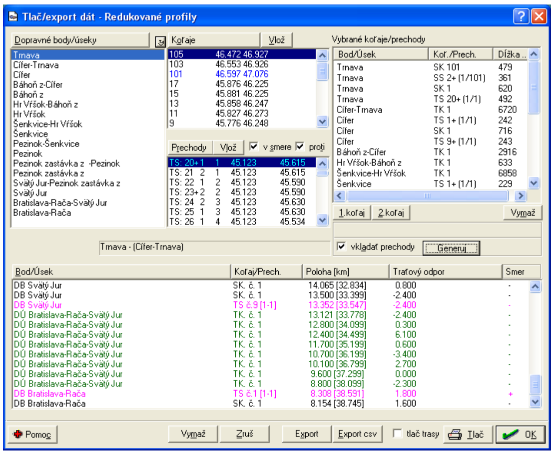


Fig. 8 Export data about rigging and curvature

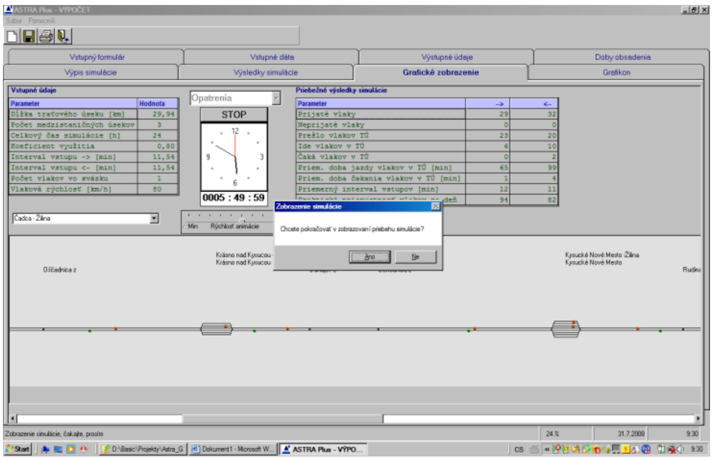


Fig. 9 Window of graphical simulation

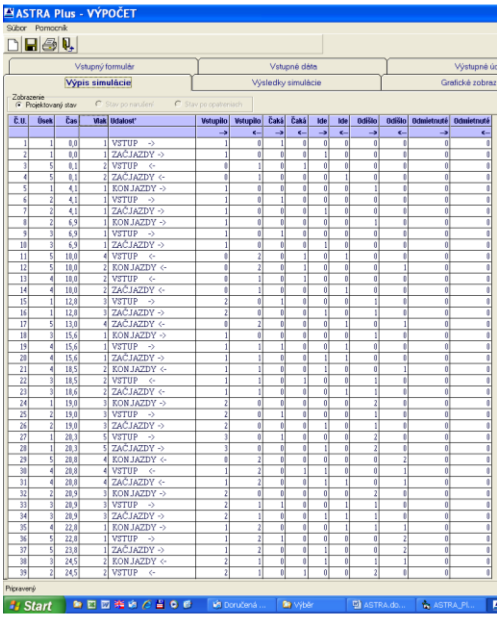


Fig. 10 List of simulation

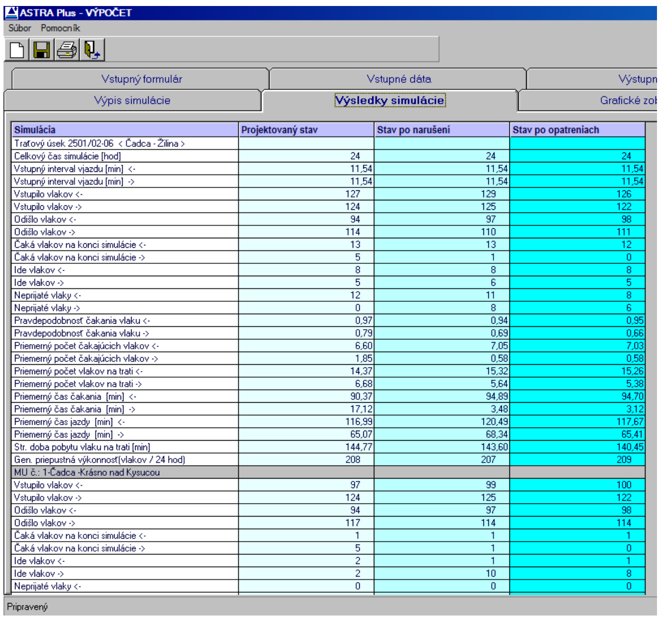


Fig. 11 Results of simulation

The algorithm for data transfer and transformation was based on data export methods from other software products with focus on data about transport connection points, speed profiles as well as direction and gradient ratio (Fig. 8), valid for reduced profiles. This simulation is preceded in real time with focus on technological solution of problem object. Other real outputs of simulation is overview in table form (Fig. 9).

Other real output of simulation is overview table, which displays all needed data (Fig. 10). Due to the fact, that detailed list of all results was too detailed for practical using by experts in field, therefore programmers of ASTRA decided to create summary output of simulation results (Fig. 11). This window is designed to evaluate projected state, state after violation and state after application of measures.

There may occur situations on railway network, when the transit performance is lower than normal. Management of train traffic on this section is then crucial for performance across the line. A process for the management of traffic is in case is totally different from the existing one. The result of the project - a software ASTRA+ can evaluate possible situations when the transit performance of railway network is limited. The program can draw graph train service as well. This enables fast optimization of management of train traffic in particular space.

5. Conclusion

In railway network there could appear some situations when, compared to usual situations, some limitations in the transport capacities on certain sectors appear. Organisation of the railway transport in this sector is crucial for the transport capacity of the whole route. The methods of management work are in this case totally different from the usual methods.

The extent and consequences of emergencies and various crisis phenomena affecting on the transport infrastructure leads often to a substantial reduction in the transit performance or total interruption of traffic flows. The most serious impact on limitation of transport of passengers and goods would be in case of road and rail transport. When deciding on the renewal of its capacities and traffic, the computer simulations plays an important role. Project ASTRA+ offers optimal management of rail operations with focus transit performance.

The most significant contribution of program product is its specific and original usage of processes for calculation of minimal time interval for train ride in real route sectors. The aim of this article is to explain new knowledge from field of railway transport planning theories in specific conditions and to present created software product ASTRA+. Developed software tool enables:

- selection of the rail track section;
- selection of the traction unit;
- choice of standard wagon kits;
- choice of resistance wagon kits;
- adjustments of input data displayed on the track section according to the particular situation and distortions;
- draft of the measures to the distortion of railway track sections;
- detailed calculation of travel times with for standard train in the selected route section;
- input data changes on the railway track sections according to the particular breach;
- calculate the transit performance on a limiting track section;
- generating a train timetable according to current technical conditions.

Acknowledgments

The article was supported by the project VEGA 1/0240/15 Process model of critical infrastructure safety and protection in the transportation sector and the project Centre of excellence for systems and services of intelligent transport II, ITMS 26220120050, co-financed by the European Regional Development Fund.

References

1. **Banks, J.** Handbook of Simulation: Principles, Methodology, Advances, Applications and Practice. John Wiley & Sons, New York, 864 p., ISBN 978-0-471-13403-9.
2. **Davidovic, B.; Čekerevac, Z.** 2005. Integration of the System for Providing Quality and Controlling Into Logistic Processes, In: Proceedings of 15th International Scientific Conference Transport 2005, Sofia, Bulgaria.
3. **Dvořák, Z.; Čekeravac, Z.; Milata, I**. 2009. Operational planning of railway transport in crisis situations in case of Slovakia and Serbia, In: Mechanics Transport Communications, Academic journal, Sofia, Bulgaria. Issue 3, p. IV-26- IV-30, ISSN1312-3823.
4. **Dvořák, Z.; Soušek, R.; Englich, J.** 2007. Preparation for solution of crisis situations in railway transport in Czech Republic. In: Logistyka i Transport 1(4): 23-26.
5. EUROPA. 1995-2008. European Commission proposes increased Protection of Freight Transport against Terrorism. [online]. In: EUROPA – European Communities Homepage. [cit. 2006-05-05]. Web: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/242&format=HTML&aged=0&language=EN&guiLanguage=en
6. **Kitamura, R.; Kuwahara, M;** 2005. Simulation Approaches in Transportation Analysis: Recent Advances and Challenges. Springer; 1 edition, 400 p, ISBN 978-0387241081.
7. **Kleprlík, J.; Mazač, P., Šourek, D.** 2009. Critical activities in rail freight (in Czech). In: Electronically Magazine

”Perners Contacts”, 3/2009, University of Pardubice, p.125-129, Czech Republic, ISSN 1801-674X. Web: http://pernerscontacts.upce.cz/ PC_152009.pdf

8. **Kleprlík, J.** Regulatory measures in the transport crisis conditions (in Czech). In: Proceedings of 13th international conference “Crises Situations Solutions in Specific Environment”, FŠI ŽU, Žilina, Slovakia p.357-364, ISBN 978-80-8070-847-4.
9. **Kleprlík, J.; Rathouský, B.; Bečičková, M.** 2008. The Usage of Multicriterial Analysis for Determining Priorities and the Evaluation in Transport. In: Scientific papers of the University of Pardubice, Series B - The Transport Faculty, 14: 159-168, University of Pardubice, Czech republic, ISSN 1211-6610.
10. **Máca, J.; Leitner, B.** 2008. Methods of Multicriterial Decision Making in Crisis management of Transport (in Slovak). In: Proceeding of International Scientific Conference “Crisis states and Transport”, University of Pardubice, Transport Faculty, Pardubice 2008, Czech Republic, pp. 45-49, ISBN 978-80-86530-49-9.
11. **Máca, J.; Leitner, B.** 2002. Operational research for security management (in Slovak). Košice, Slovakia, 181 p. ISBN 80–88829–39–9.
12. **Milata, I.** 2001. Queuing theory in military transport (in Slovak). VF VŠDS. Žilina 2001, Slovakia.
13. **Milata, I.; Kašpar, V.; Rošteková, L.; Dvořák, Z.** 2005. Mathematical support of crisis planning. In: “Communications”, Scientific papers - University of Žilina, Slovakia, 3/2005, p. 64 - 68, ISSN 1335-4204.
14. **Novák, L.; Milata, I.** 1996. Application of „3 sigma theory“ to Erlangs distribution of random variable. In: Proceedings of X. International Scientific Conference TEMPT´97, Higher Military School of Transport, Sofia,, Bulgaria 1996.
15. **Soušek, R.** 2002. Crisis management in transport, (in Czech). Institute of Jan Perner, 2002 Pardubice, Czech Republic. ISBN 978-80-86530-06-27.
16. **Soušek, R.; Dvořák, Z.** 2009. Risk identification in critical transport infrastructure in case of central Europe with focus on transport of dangerous shipments. In: Proceedings of the 13th world multi-conference on systemics, cybernetics and informatics - WMSCI 2009, International Institute of Informatics and Systemics, Orlando, Florida, USA, 2009, p.374-377. ISBN 978-1-934272-62-6.
17. **Sventeková, E.** 2005. Risk analysis in transport systems, (in Slovak). In: Proceedings of conference LOGI 2005, University of Pardubice, Pardubice, Czech Republic. p. 219-223, ISBN 80-86530-25-6.
18. **Sventeková, E.** 2006. Principles of security enhancing on transport infrastructure (in Slovak). In: Proceeding of conference Rescue services 2006, VŠB-TU, Ostrava, Czech Republic, p. 394-399, ISBN 80-86634-88-4.
19. VTT. 2006. Research. Identification of Transport Unit - TRACKIDEF [online]. In: VTT Homepage. [cit. 2006-05-15]. Web: http://www.vtt.fi/vtt_search.jsp? target=tutk& fuzz=true&search=trackidef
20. **Zhou, O.; Wang, D.; Chen, L.** 2010. A Method of Computer Simulation for Train Running Process. In: 2nd International Conference on Computer Modeling and Simulation - ICCMS 2010, 3: 179-181.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Development of Concentrated Parameter Distribution-Type Model for the Examination of Gas Turbine Engines Supplied by Alternative Fuels

B. Varga[1], L. Kavas[2], K. Beneda[3], K. Fehér[4]

[1]*National University of Public Service, H- 5008 Szolnok,P.O.B.1., Hungary E-mail: varga.bela@uni-nke.hu*
[2]*National University of Public Service, H-5008 Szolnok, P.O.B.1., Hungary E-mail: kavas.laszlo@uni-nke.hu*
[3]*Budapest University of Technology and Economics, H-1521 Budapest, Pf. 91, Hungary E-mail: kbeneda@vrht.bme.hu*
[4]*National University of Public Service, H- 5008 Szolnok,P.O.B.1., Hung. E-mail: feher.krisztina@uni-nke.hu*

Abstract

Nowadays, the aviation industry mostly uses gas turbine engine powered aircraft. The modern high-performance computers strongly support the examination and understanding the deeper relations of gas turbine engine processes. The objective of our paper to present the development of the gas turbine engine calculator programme, which with its flexible operation is suitable to examine not only one basic type but any type of gas turbine engine. Above all it can provide parameter sensitivity examination and calculate the different operational points of gas turbine engines. During the development we try to broaden its capability to examine how the different fuels affect the engine performance indicators. The programme uses Visual Basic for Applications language and the management surface uses Microsoft Excel. Its operation was checked by the available data of existing gas turbine engines.
KEY WORDS: *Concentrated parameter distribution-type model, Specific Net Work Output, Thermal Efficiency, alternative fuels, hydrogen, natural gas*

1. Introduction

Unfortunately, aviation by the combusted fuel releases a large amount and lot of different pollutants into the atmosphere. Considering the climate change, the most serious problem is the carbon dioxide emission. According to the most recent data from the Intergovernmental Panel on Climate Change (IPCC), air traffic (domestic and international) is responsible for 2% (814 million tons) of the global carbon dioxide emissions generated by human activity, of which international air traffic produces at about 1.3%. However, considering the expected growth rate of aviation, this amount of emitted carbon dioxide would be triplicated in the next 30 years without additional measures. Since one of the main objectives of the ICAO[1] is to support of an economically sustainable and environmentally responsible civil aviation sector, ICAO has decided that with its Member States and in cooperation with the relevant organizations, does as much as possible to achieve the global 'carbon neutral' growth of international aviation. It means that the net carbon dioxide emissions from the international aviation industry cannot exceed the 2020 level of carbon dioxide emission. This basket includes numerous measures from aircraft technologies to operational improvements, alternative fuels, and market-based measures (MBM) [1]. In the next chapters with the the gas turbine engine calculator programme we examine how the different alternative fuels affect the gas turbine engine performance and its carbon dioxide emission.

For the analyzes we have chosen two vital performance indicators of gas turbine engines, namely the Thermal Efficiency (TE) and the Specific Net Work Output (SNWO) of the gas turbine engines. Both of them are primary performance indicators and suitable for the evaluation of any kind of effect on the operation of gas turbine engines [2].

SNWO ($w_{net}(\pi)$), is the desired output of the thermodynamic cycle. In accordance with the second law of thermodynamics the mechanical work is always less than the input heat and in addition the friction in the real gas turbine components causes some more heat loss. This heat is dissipated as waste heat into the environment.

$$w_{net}(\pi) = w_e(\pi) - w_c(\pi). \tag{1}$$

TE ($\eta_{th}(\pi)$), in general, energy conversion efficiency is the ratio between the useful output of a device ($w_{net}(\pi)$) and the input, in energy terms. For thermal efficiency, the input ($q_{in}(\pi)$) to the device is heat, or the heat content of a fuel that is consumed.

$$\eta_{th}(\pi) = w_{net}(\pi) / q_{in}(\pi), \tag{2}$$

here $w_c(\pi)$ - specific compression work, J/kg; $w_e(\pi)$ - specific expansion work, J/kg; $q_{in}(\pi)$ - specific input heat, J/kg; π – Compressor Pressure Ratio.

[1] ICAO: International Civil Aviation Organization, the United Nations' Organization and highest level coordinator of civil aviation

2. Combustion Products from Stoichiometric Combustion of Fuels

Our study focuses on three fuels, kerosene, natural gas and hydrogen. First of all, their stoichiometric combustion was under scrutiny. Of course, the composition of both kerosene and natural gas can vary somewhat. In case of kerosene, the chemical equation of stoichiometric combustion can be set up by choosing one of its representative component. Based on the composition of the kerosene the most dominant component is the $C_{10}H_{22}$ hydrocarbon. The chemical reaction Eqs.(3) and 4. specifies the amount of air needed for the stoichiometric combustion of one kg fuel and its reciprocal, the fuel to air ratio (*f*) the ratio of fuel mass flow ($\dot{m}_{fuel}$) and air mass flow ($\dot{m}_{air}$).

$$\mathrm{C_{10}H_{22}} + Y \cdot \mathrm{O_2} + 3{,}76 \cdot Y \cdot N_2 = 10 \cdot \mathrm{CO_2} + 11 \cdot \mathrm{H_2O} + 3{,}76 \cdot Y \cdot \mathrm{N_2}\,. \tag{3}$$

It is easy to see that the product of chemical reaction is carbon dioxide and water (steam). In optimal case, nitrogen is not involved in the reaction, but as an ingredient of air as a gas mixture, it must be taken into account when we determine the fuel to air ratio. In Eq. (3). '*Y*' is the number of O_2 molecules required for perfect combustion. Since combustion products contain a total of 31 oxygen atoms, in Eq. (3) '*Y*' is equal 15.5. Using atomic masses (*M*) in Eq. (4) the fuel to ratio can be calculated [3].

$$f = \frac{\dot{m}_{fuel}}{\dot{m}_{air}} = \frac{10M_C + 22M_H}{31M_O + 31 \cdot 3{,}76M_N} = \frac{10 \cdot 12 + 22 \cdot 1}{31 \cdot 16 + 31 \cdot 3{,}76 \cdot 14} = \frac{142}{2127{,}8} = 0{,}0667\,. \tag{4}$$

The reciprocal of the fuel to air ratio gives that for the stoichiometric combustion of one kg fuel about 15 kg of air is needed while the combustion product consists of approx. 3.1 kg of carbon dioxide and 1.4 kg of water (vapour). Similarly, the results of calculations for methane and ethane as well as for hydrogen are given in Table 1 below.

Table 1

The data of perfect combustion of the examined fuels

Stoichiometric combustion	**kg air/kg fuel**	**kg CO_2/kg fuel**	**kg H_2O/kg fuel**	**kg fuel/kg air**	**Fuel heating value [MJ/kg]**
$C_{10}H_{22}$ (kerosene)	14.985	3.099	1.394	0.0667	43.217
CH_4 (methane)	17.160	2.750	2.250	0.0583	50
C_2H_6 (ethane)	16.016	2.933	1.800	0.0624	47.5
H_2 (hydrogen)	34.320	0.000	9.000	0.0291	118.429

As the very large percentage of natural gas is methane (97%), we are examining the burning of methane gas as natural gas. From Table 1, it can be seen that combustion of natural gas produces significantly less carbon dioxide while its heating value is higher than that of the kerosene.

By improving the conditions of combustion, the amount of the emitted carbon dioxide and water vapour cannot be reduced, but only by decreasing the fuel consumption itself using more economical engines, aerodynamically better airframe and wing design, mass reduction (aircraft technology) and operational improvements and at last but not least burning alternative fuels. Of course, the combustion is not perfect in the combustors of gas turbine engines, so other combustion products (pollutants), like nitrogen oxides, sulphur oxides, carbon monoxide, soot, unburnt fuel particles are also generated, see Table 2. The emission of these pollutants can be slightly reduced by optimizing the combustion process improving the fuel nozzles and combustor itself.

Table 2

Average combustion products of one kilogram of kerosene burnt in gas turbine engine combustor

pollutant	CO_2	H_2O	NO_x	SO_x	CO	unburnt fuel	soot
gram/kg fuel	3100	1394	9-15	0.3-0.8	0.2-0.6	0-0.1	0.01-0.05

These pollutants are responsible for the ground-surface pollution and basically significant in the vicinity of airports, and in this respect it is related to the phases of taxiing, takeoff and landing, as well as climbing and approach of the aircraft. As they directly affect the close environment of the airports and accordingly the population and nature there, this became the focus of attention and became the subject of early regulations. Accordingly, ICAO has been pushing ever stricter regulations from the 1960s to reduce these pollutants.

The high-atmospheric pollution, caused by carbon dioxide and water vapor, is not so obvious and immediate, but may be its harm can be more severe in the future of mankind, taking into account the already present phenomena of climate change and ozone depletion. Water vapour can be said harmless, as a naturally occurring material that is an integral part of our lives. However, the effects of high-atmospheric emissions of water have not yet been clarified, but environmental and climate protection experts are increasingly concerned about the large volumes of water vapour entering

into the atmosphere. However, concerning the climate change the main "enemy" is the carbon dioxide. As can be seen from Tables 1 and 2. each tonne of combusted fuel produces approx. 3.1 tonnes of carbon dioxide.

In accordance with it the subject of further investigations is also the carbon dioxide, namely how alternative fuels can influence carbon dioxide emission and engine performance parameters.

3. Impact of Alternative Fuels on Engine Performance Parameters

In this chapter, we examined the effect of the above mentioned three fuels on the gas turbine engine performance parameters, namely the Specific Net Work Output and Thermal Efficiency using the concentrated parameter distribution-type model, discussed above. In each case, the base value is given by the combustion of kerosene. Differences, compared to the base values, are depicted in percentage.

The Turbine Inlet Temperature is 1750 K, which is fairly high, but it is not extraordinarily, regarding the current technological level. The efficiencies and losses are as follows: the compressor polytrophic efficiency is 0.85, the expansion polytrophic efficiency is 0.88, the combustor efficiency is 0.97, the total pressure loss factor of the engine is 0.941, and finally the mechanical efficiency is 0.97.

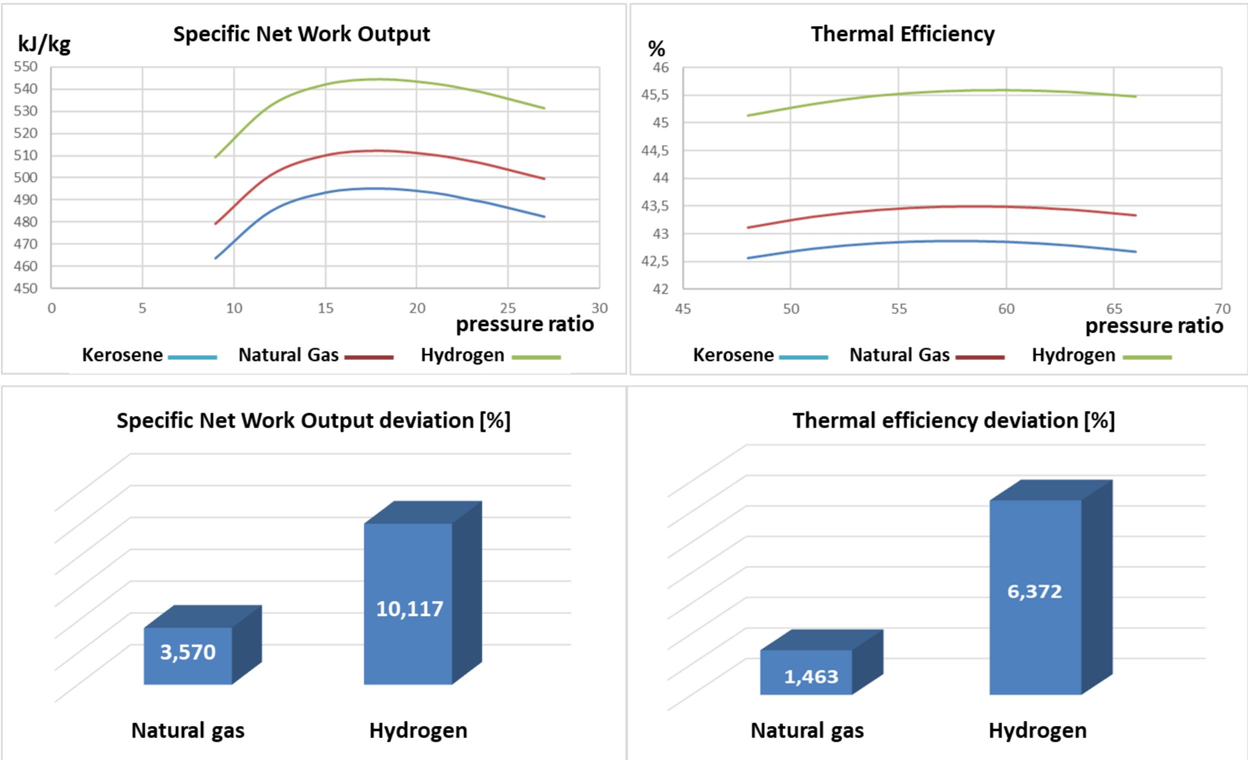


Fig. 1 Deviation of maximum SNWO and TE of natural gas and hydrogen from the base given by the combustion of kerosene

It is noted that the real gas turbine engine cycle, within given temperature limits and component efficiencies and losses, has optimums of both Specific Net Work Output and Thermal Efficiency, which are functions of compressor pressure ratio. These two optimums (and the related compressor pressure ratios) are significantly different from each other, accordingly, both optimum cannot be produced simultaneously. With our model the compressor pressure ratios of the maximum Specific Net Work Output, the maximum Thermal Efficiency, and their values can be calculated.

The results were illustrated by the Excel graph editor. The optimums, we mentioned above, are well characterised by the compressor pressure ratio, see in Fig. 1. The diagram also shows that the pressure ratio of the maximum Specific Net Work Output is 17:1 and for the maximum thermal efficiency is approx. 60:1. These compressor pressure ratios do not change significantly depending on the type of combusted fuel. However, the Turbine Inlet Temperature in all cases is 1750 K and the mass flow rate difference is negligible (~ 1 kg due to specific values) both the Specific Net Work Output and the Thermal Efficiency increases considerably compared to the values produced by the kerosene. For Thermal Efficiency, the relative values shown in Fig. 1 represent an absolute Thermal Efficiency increase of 0.63 and 2.71% in case of natural gas and hydrogen respectively.

Of course, no gas turbine engine will be expected, that its operational point would be adjusted to either of the two extreme operational points (pressure ratio 17:1 or 60:1, see two top diagrams in Fig. 1), but to some intermediate optimum pressure ratio where both Specific Net Work Output and Thermal Efficiency are less than their maximum values, but gives a good compromise. In our case the chosen compressor pressure ratio is 23:1 and the related data are collected in Table 3.

For this pressure ratio the deviation of Specific Net Work Output and Thermal Efficiency from the base given by

the combustion of kerosene was also examined. In this case, there are similar differences in both the Specific Net Work Output and the Thermal Efficiency, see in Fig. 2 left, like it was in the two extreme operational points (pressure ratios) in Fig. 1, which implies that the deviation does not change significantly in the possible operational range. We also determined the deviation of Specific Fuel Consumptions, see in Fig. 2 right, which was shown also very significant drop to the base value.

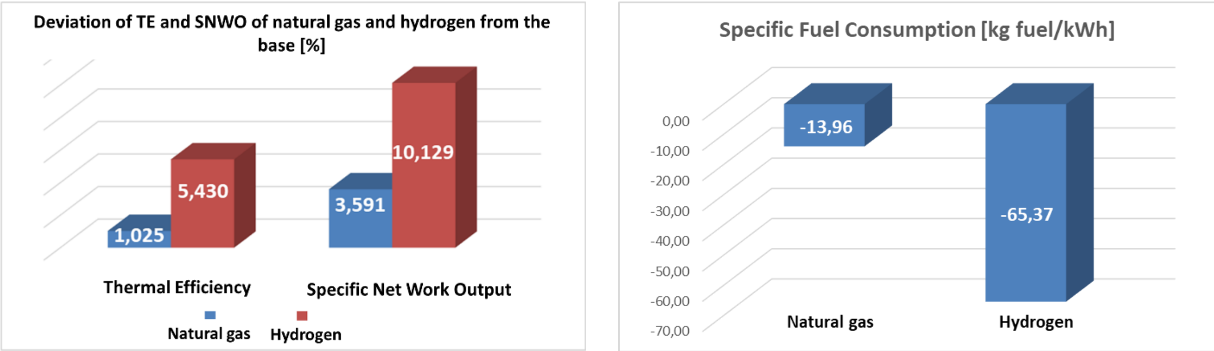


Fig. 2 Deviation of Specific Net Work Output and Thermal Efficiency (left) and Specific Fuel Consumption (right) of natural gas and hydrogen from the base given by the combustion of kerosene

Table 3

Summarised results of the examined operational point

Compressor Pressure Ratio: 23:1; Combustor Inlet Temperature: 800 K; Turbine Inlet Temperature: 1700 K					
	kg fuel/kg air	kg CO2/kg air	kg H2O/kg air	SNWO [kJ/kg]	TE [%]
Kerosene	0.0286	0.0886	0.0398	489.87	39.613
Natural gas	0.0255	0.0701	0.0573	507.46	40.019
Hydrogen	0.0109	0.0000	0.0982	539.49	41.764

Since the fuel consumption is available and the air mass flow rate is 1 kg/s in all cases, consequently this also gives us the value of fuel to air ratio (*f*) (kg fuel/kg air in Table 1). Partly we chose the compressor pressure ratio to 23:1, because in this case the Combustor Inlet Temperature is at about 800 K. This temperature is identical with the initial temperature of the diagram created by Technical Team of the NATO on the topic of Performance Prediction and Simulation of Gas Turbine Engine Operation for Aircraft, Marine, Vehicular, and Power Generation [4] in Fig. 3.

Comparing the fuel to air ratio resulted by the model (first column in Table 1) to the diagram, red points in Fig. 3, there is a considerable alignment between them verifying the correctness of our results.

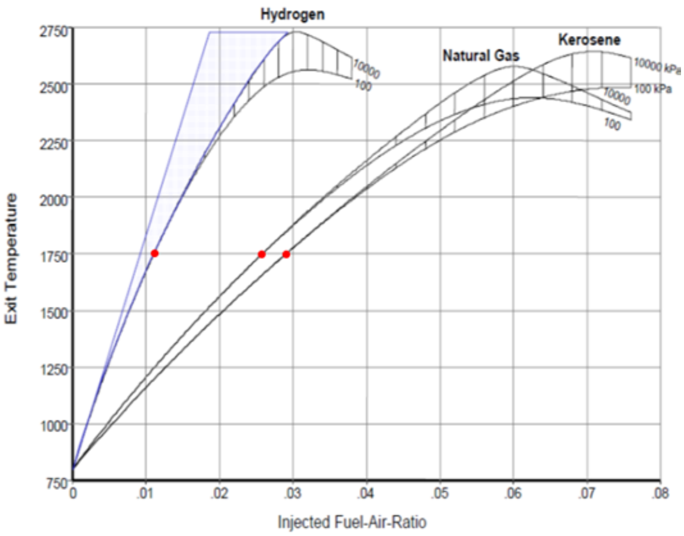


Fig. 3 Theoretical temperature versus fuel to air ratio diagram for the examined fuels [4]

Fig. 4 shows the carbon dioxide and water vapour emission for one kg of air consumption and one kWh work. The reduction in carbon dioxide emissions is already apparent in natural gas, and in case of hydrogen, of course, it is zero. Water vapour emissions increases in both cases. The difference is even more significant if the base of specification is kWh.

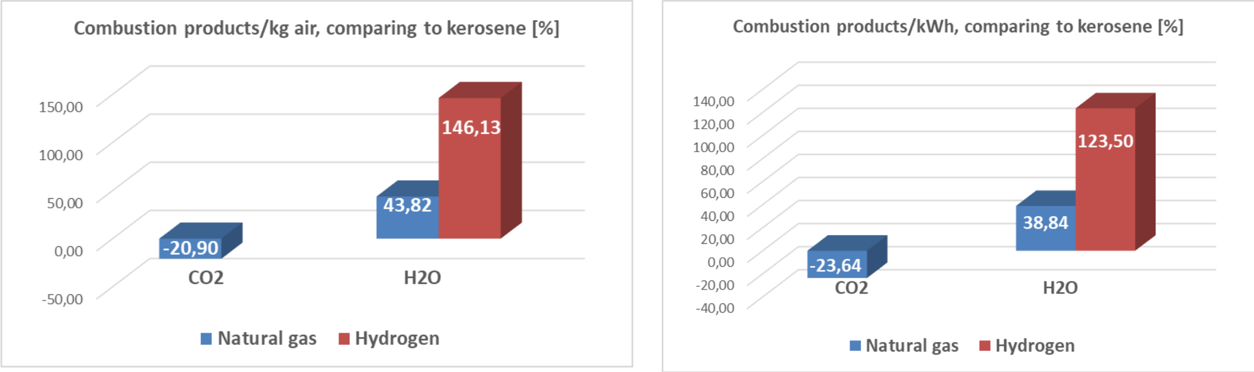


Fig. 4 Deviation of the combustion products of natural gas and hydrogen from the base given by the combustion of kerosene

4. Conclusions

In this paper, we have not investigated other problems with the examined fuels, which makes their use particularly difficult in aircraft gas turbine engines. These include storage on board or increased fire risk, especially for hydrogen. In case of industrial gas turbines this is a less serious problem and many of these gas turbines are fuelled by natural gas. Analysing the data, both fuels have positive effect on each indicator of the gas turbine engine operation. Understanding the impacts on operation, it is worth examining separately the components of the gas turbine. There is no difference in the compressor. For all three fuels, the same mass flow rate of air is compressed with the same pressure ratio, which required the same compressor work. In order to reach the same Turbine Inlet Temperature (1750 K) in the combustion chamber, for both alternative fuels, less fuel was needed due to their higher Fuel Heating Value, which reduced the Specific Fuel Consumption. The same gas temperature, pressure and mass flow rate in the turbine inlet section does not mean that the same performance data can be expected in all three cases. This is due to the fact that in this cross section the gas composition is significantly different. The water (vapour) is considerably higher and the carbon dioxide content is lower in the combustion product of natural gas, and the combustion product of hydrogen, of course, does not contain carbon dioxide. We can conclude that higher water (vapour) content results higher Specific Net Work Output and better Thermal Efficiency consequently any fuel with lower carbon content and higher hydrogen content improves the engine performance and in the same time decreases the carbon dioxide emission.

Acknowledgement

This work was supported by the European Regional Development Fund (GINOP 2.3.2-15-2016-00007, “Increasing and integrating the interdisciplinary scientific potential relating to aviation safety into the international research network at the National University of Public Service - VOLARE”). The project was realised through the assistance of the European Union, and co-financed by the European Regional Development Fund.

SZÉCHENYI 2020
MAGYARORSZÁG KORMÁNYA
Európai Unió
Európai Regionális Fejlesztési Alap
BEFEKTETÉS A JÖVŐBE

References

1. Why ICAO decided to develop a global MBM scheme for international aviation? [online cit.: 2017-12-23]. Available from: https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ1.aspx
2. **Varga, B.; Óvári, Gy.; Rozovicsné Fehér, K.; Tóth, J.** 2015. Specific Net Work and Efficiency Analyses of Gas Turbine Engines Using Thermal Mathematical Model, Proceedings of 19th International Scientific Conference Transport Means, 781 p.
3. **Cumpsty, N.** 2003. Jet Propulsion, Cambridge University Press, Cambridge, 450 p.
4. Component modelling for system models, [online cit.: 2013-07-16]. Available from: http://ftp.rta.nato.int/public/PubFullText/RTO/TR/RTO-TR-AVT-036/TR-AVT-036-04.pdf, (16/07/2013)

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Complex Approach to Seaport Attractiveness and State Competitiveness Advantages

J. Belova[1], R. Mickienė[2], E. Valionienė[3]

[1]*Lithuanian Maritime Academy, I. Kanto g. 7, LT-92123, Klaipeda, Lithuania, E-mail: j.belova@lajm.lt*
[2]*Lithuanian Maritime Academy, I. Kanto g. 7, LT-92123, Klaipeda, Lithuania;*
Mykolas Romeris university, Ateities g. 20, LT-08303, Vilnius 3, Lithuania E-mail: r.mickiene@lajm.lt
[3]*Lithuanian Maritime Academy, I. Kanto g. 7, LT-92123, Klaipeda, Lithuania;*
Mykolas Romeris university, Ateities g. 20, LT-08303, Vilnius 3, Lithuania E-mail: e.valioniene@lajm.lt

Abstract

Maritime transport sector, seaport and shipping, create preconditions for maritime states to implement strategically significant national market regulatory measures in order to create added value to the national economy. Creation of added value is the strategical objective of modern state-owned companies working in the global market and the effectiveness of governance model becomes strongly related with the organizational attractiveness and competitiveness. Sustainable governance model could be applied for the multidimensional comparison of different governance models and to evaluation of competitiveness advantages.
KEY WORDS: *port performance, port attractiveness, competitiveness, complex evaluation, effective governance, sustainable governance model.*

1. Introduction

Maritime transport sector, seaport and shipping, create preconditions for maritime states to implement strategically significant national market regulatory measures in order to create added value to the national economy. The state seaport is an element of the maritime transport sector also it is important unit of public sector and it could be analyzed as an area of activities of the whole state and region in the transport sector which create preconditions for improving the international, political and economic positions of maritime states in the region. This point of view is important in the context of globalization of the whole logistic supply chain because the role of effective governance is increasing rapidly. Therefore the efficiency of the state seaport from the management and economic perspective is one of the features of the attractiveness of the maritime transport sector in the region, which directly influences the competitiveness of the entire economy of the country. The peculiarities of the efficiency of the maritime transport sector have to be analyzed in a complex manner and its complexity can be revealed in various ways: optimal and effective distribution and exploitation of state-owned resources, effective private capital involvement by strengthening the supra-structure of the seaport, attractiveness for the cargo consignor and the consignee, performance, socio-economic progress and other.

In order to maximize the positive impact of the activities of the maritime transport sector on the country's economy and its competitiveness, a shift in the seaport's mission is observed: the aim to increase the productivity by the growing volume of cargo has shifted to the goal of creating added value to the stakeholders. Based on this point of view it is important to take into consideration the nature of seaport and shipping activities because it is a connection of whole global supply chain and the attractiveness of seaport means the wider range of stakeholders, the bigger amount of added value for the national economy and increased national competitiveness. Earlier theoretical justification of the relationship between the value-oriented governance of state seaport and national competitiveness found out that state seaport governance is driving the whole maritime industry clusters, which are working on the principles of complex adaptive systems or like whole ecosystem. Based on the research results the state seaport governance is working on the principles of added value creation based on the sustainable governance model for the increasing of the attractiveness of regional economy, so the object of research is relation between seaport attractiveness and state competitiveness advantages.

The aim of this research is to explain relation between seaport attractiveness and state competitiveness advantages. The objectives of research are: (1) to describe state seaport governance model's influence on the attractiveness of state-owned seaport; (2) to analyse port performance. Research methods: analysis of scientific literature, statistical and financial analysis, multi-criteria analysis based on the principles of modeling.

2. State Seaport Governance Model Influence on the Attractiveness of Maritime Sector

The globalization process of the international logistics chain has significantly affected not only the private capital sector, but the public sector as well. Such an impact manifested itself through the transformations of management forms and scientific paradigms, which were preconditioned by the imbalance between intensive and dynamic changes in the environment and the rigid, complex and ever-expanding state management apparatus, defined by the vast variety of procedures and functions. The public sector has become a highly complex system of allocating economically significant

national resources, which operates in an ever-changing environment characterized by high uncertainty. These global market conditions influences for the demand of new and more effective governance models not only in the private sector, but also in public sector especially in the area of state-owned enterprises, because they are powerful tool for the national economy regulation and national recourses allocation.

The application of the notions of the new public governance in the research on effective management of state enterprises expanded the field of issues of effective management of state-owned seaports. Said application also formed the preconditions for the application of the complexity approach, and the establishment of the interpretative approach to investigated phenomena and their interrelationships. The concentration of the principles of the theory of effective governance of state-owned enterprises [1] presupposes the interconnectivity of high productivity with the efficiency of management through a variety of measurable and mutually comparable criteria (Fig. 1):

– efficiency of technological operations: absolute performance, productivity and performance indicators;

– efficient financial management: profitability, return on capital, real added value, return on investment;

– effectiveness of strategic management: cooperation and partnership, competitiveness and attractiveness, meeting the needs of stakeholders, leadership and mission clarity.

– legal-political criteria for management efficiency: financial and institutional autonomy and accountability, specialized policy of integrated and sustainable sectorial and/or regional development.

These criteria describe unified model of effective governance of state owned enterprises in the cumulative and multiplicative ways and from this point of view the effective governance model is adequate for the state-owned seaports evolution from the first generation seaports shift to fourth generations [2], but also it is parallel for the globalization processes and naturally shifting from the volumes to the added- value in the maritime sector governance policy [3].

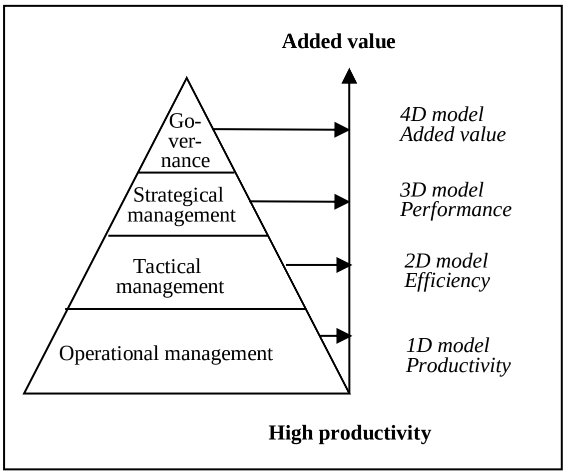


Fig. 1 Complexity of effective management concept [1, 2]

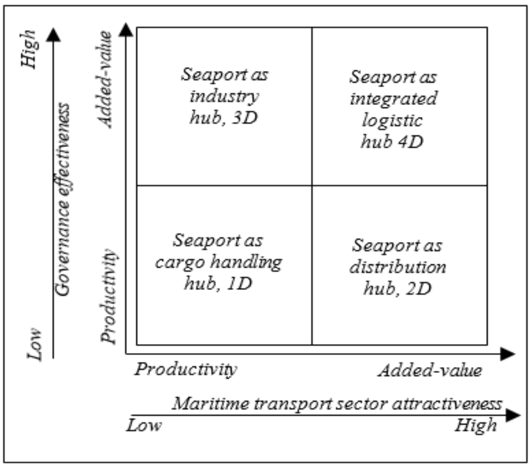


Fig. 2 Maritime transport sector attractiveness levels matrix model

Analysis of the elements of effective state-owned seaport governance in theory of effective management point of view supposed to form a multi layered complex structure [4]. This structure combine the qualitative characteristics of management attributes with the quantifiable indicators in a multidimensional model (Fig. 1) which could be applied in analyzing the seaport governance model in the dynamic logistics chain, where the efficiency of seaport governance may be measured in a complex manner by combining the basic productivity, efficiency, effectiveness indicators and the indicator of external environment into one multi-criteria model (Fig. 2). The approach may be employed to identify the significance of the seaport for increasing the logistic connectivity of the transport sector, which creates preconditions for assessing the attractiveness of the maritime transport sector through the integrated logistic performance indicator.

To summarize the maritime transport sector attractiveness level, there is a possibility to establish the link between maritime sector governance efficiency and sector attractiveness. It can be defined by the matrix model (Figs. 1 and 2), which generated the scope of attractiveness indicators: productivity, efficiency, performance, effectiveness, and added value indicators. These arguments show that, the country’s competitiveness can be described by the sustainable added value indicators, which measures whether a maritime transport sector creates extra value while ensuring that every environmental and social impact is in total constant, and increasing of added value in maritime sector creates and raises attractiveness of the maritime transport sector. But as scientific researches [5-8] found out, it is strongly related with the sustainable business models and it means that effective maritime governance concept suppose the requirements for the finding of effective governance model which could be described on the basis of sustainable governance model (SGM). And this conception is developed on the basis of contingency, complexity theories and on the principles of organizational ecosystems: the basic productivity, efficiency, performance and connectivity values are combined with a wider social environmental indicators supposing the added value concept.

Based on the theoretical prerequisites and principles of SGM, related governance and process management criteria could be found in the context of SGM:

– SGM as flourishing business canvas [5]: further work is under way to determine applicability across a number

of sectors, sizes, and stages of organizational development;

– SGM as a value mapping tool [6]: the tool is envisaged to have applicability to all organizations, new startups, established large corporations, public sector and NGOs;

– SGM as triple layered model [7]: organizations whom wish to innovate upon their current business model and create concepts of more sustainable business models;

– SGM as infrastructure development model [8]: private and public decision maker for infrastructure investments (local delivery network operator, municipal and others).

But in the context of modelling of maritime sector attractiveness on the base of SGM the main governance and process criteria could be described (Table 1). Governance principles provide means to increase the possibility of designing model, but without pre-defining a distinct outcome, and process criteria describe how to get there and inform the design of suitable tools accordingly. This point of view is strongly related with the conception of effective maritime governance and helps to identify main maritime sector attractiveness and competitiveness advantages. Based on the theoretical background, main governance principles could be identified: sustainability, extended added- value, system thinking and stakeholders involving. These criteria could be connected through the different scientific explanations of SGM, but as it found out the main key parameters have dominant role in different SGM explanations as attracting factors: direct and indirect value creation through the involvement the stakeholders through the different direct and indirect benefits values. System thinking criteria could be called as extending criteria of effective governance model and it has such parameters as interpreting organization as social network system with the emergent behavior and dynamic relations. And all of these governance criteria of SGM are oriented to the wider economic-social benefits and national competitiveness in the context of effective governance theory. Process criteria in SGM also are related with the extending of added value, but they are more concrete an oriented into to the internal and external recourse usage and could explain productivity, efficiency, performance indicators in the effective governance theory in the context of maritime sector attractiveness.

Table 1

Complex model of sustainable governance model as the prerequisite of attractiveness [9, 10]

<table>
<tr><th colspan="2">Criteria / Model</th><th>Flourishing business canvas</th><th>Value mapping tool</th><th>Triple layered model</th><th>Infrastructure development model</th></tr>
<tr><td rowspan="4">Governance criteria</td><td>Sustainability</td><td>Strong sustainability</td><td>Planning processes</td><td>Broad triple bottom line approach</td><td>Wider social and environmental benefits to new actors and society</td></tr>
<tr><td>Extended Added value</td><td>Value creation, destruction among actors and value networks as social systems</td><td colspan="2">Different multiple forms of value: destroyed, missed, new value opportunities</td><td>Direct and indirect values</td></tr>
<tr><td>System thinking</td><td>Business as a social system within economy, society, and environment</td><td>System-perspective of value</td><td>Life cycle an innovation</td><td>Particularities of infrastructure: multi-agent, -level, -objective</td></tr>
<tr><td>Stakeholders involvement</td><td>Co-creation of value with all an organization’s stakeholders</td><td>Multiple stake-holder view of value</td><td colspan="2">Stakeholder approach</td></tr>
<tr><td rowspan="2">Process criteria</td><td>Model components</td><td>Environmental, social, and financial context entities; new specific entities and interrelations</td><td>Different stakeholder groups</td><td colspan="2">Vertical coherence and layered system thinking</td></tr>
<tr><td>Perspective</td><td>Value networks as social systems</td><td>Network centric, value networks</td><td colspan="2">Physical/social networks, stake-holders partnerships, approach to complex systems modelling of infrastructure investment decisions</td></tr>
</table>

In summarizing it could be said, that the sustainable governance model create possibilities to establish relation between the seaport attractiveness and national competitiveness in the theory effective governance of state-owned enterprises and help to include internal (productivity efficiency, performance) and external (logistic connectivity and social-economic added value) seaport parameters into unified complex and multidimensional evaluation model.

3. The Enrichment of Phenomenon of Competitiveness

Competitiveness commonly defined as a complex economic phenomenon which has macro- (national economy), mezo- (regional economy, industry), and micro- (company economy) levels. The World Economic Forum defines the competitiveness as the set of institutions, policies and factors that determine the level of productivity of a country [11]. Follow to the conclusion that country’s competitiveness can be define with a focus on the micro- and mezoeconomic level, because nowdays competitiveness focused on the macroeconomic, political, legal, and social circumstances, that underpin a successful economy, progress in these areas is necessary but not sufficient [12]. Another way to think about what makes a country competitiveness is to consider how it actually promotes well-being of people. New approach of the socio-economic progress the actual economic state is characterized by applying an integrated analysis of various aspects of life welfare indicators (material living standards, health, employment, environment), i. e. competitive economy is a

productive one, and productivity leads to growth, which leads to income levels and improved well-being [11, 13]. The similar dimensions formed the concept of sustainable development, which assumes relations between economic, environmental and social aspects on the societal as well as on the entrepreneurial level [14]. The dilemma of sustainability in XXI century reflects the various political, social, economic and cultural circumstances that created the conditions for the start of sustainable development and are inspired by the context of neoliberal capitalism and globalization [15]. Growth that distorts ecosystem services is sometimes called "non-economic growth" as it leads to a deterioration in quality of life. This trend can be proven by population, economic growth and environmental performance indicators.

Evaluation of competitiveness, most often by way of comparison, enables to define the relative position of an object with regard to other analogical objects by the use of various competitiveness indicators. By complementing sustainable added value there is the possibility to enrich the classical model of competitivenes advantages of M. Porter [16], which states that the pursuit of competitive advantage is necessary only in areas where the country is productive: the success on the international market relates to the country's ability to efficiently use labor and capital resources. And this opinion leads to the conclusion that strength of competitive advantage of national economy depends more on differences, peculiarity, than on comparative indicators (Fig. 3).

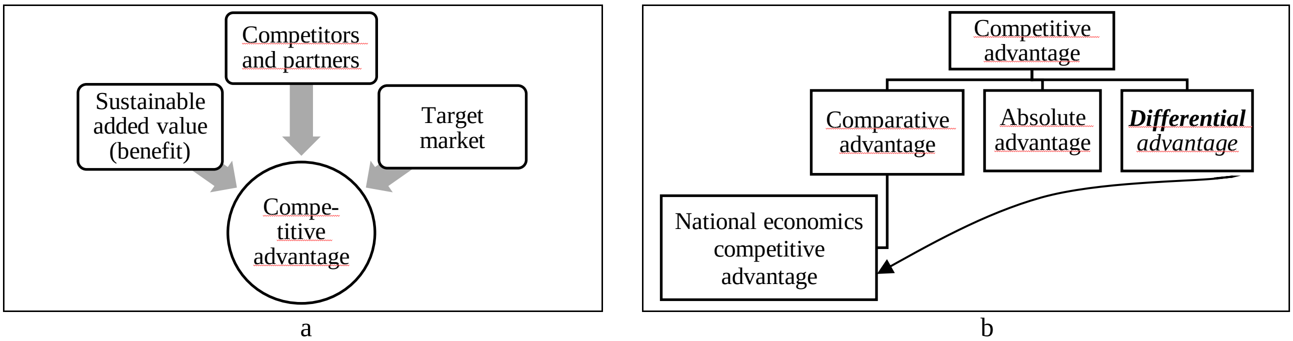


Fig. 3 Enriched view on competitiveness advantage of the national economics [14, 16]: a - factors of formation of the competitive advantege; b - factors of national economics competitive advantage

Added value in maritime transport sector, presented mainly by shipping and ports industry, in global supply chain related on differences of operated assets: enabling a charterer to provide a value added service to the sender or the carrier are different from those of the ship operator, which allows the ship operator to add value to the service to the sender. On the supply side, many industries are seeing the introduction of new technologies that create entirely new ways of serving existing needs and significantly disrupt existing industry value chains, and leads to creation of sustainable added value based on productivity. In the future, technological innovation will also lead to a supply-side miracle, with long-term gains in efficiency and productivity. The 4th Industrial Revolution has the potential to raise global income levels and improve the quality of life for populations around the world. Transportation and communication costs will drop, logistics and global supply chains will become more effective, and the cost of trade will diminish, all of which will open new markets and drive economic growth [17]. The physical footprint of supply chains is being reshaped partly in response to transport sector infrastructure improvements [18]. Logistics real estate is being restructured in response to the upgrading of transport infrastructure. Ports have strengthened their position within supply chains by diversifying their storage and handling services. Companies are generally becoming more interested in logistics facilities that combine good road access with rail or waterway transport connections.

Changes in the global market, the economic crisis and the aggressive economic development of some regions have changed the content of competition in the shipping market. The formation of shipping lines and networks have impact on the structure and volume of cargo flows and raise the economic value of shipping and the competitiveness of ports. This determines the level of significance of the transport sector in each country's economy and can be a country's competitive advantage. The intensified cooperation between shipping companies and line operators increases the various forms of alliances (common type of co-operative agreement in shipping) along main transport corridors, for example, Silk Road [19]. Companies adopted VSA policy share the available slots in their vessels in different ports so as to provide better service and reduce operating cost incurred in each container. Vessel sharing could be a viable approach for liner companies to tackle the challenge of sustainability, because is often considered to be more economically and environmentally advantageous comparing to non-vessel sharing in the fields of finance (profit maximization); economics (cost reduction and economies of scale); strategy (entry in new markets and wider geographical scope); marketing (satisfy customers with higher quality); operational (vessel planning and coordination in global scale), etc.

The arguments show that, the country's competitiveness can be described by the sustainable added value indicator, which measures whether a seaport creates extra value while ensuring that every environmental and social impact is in total constant, and increasing of added value creates and raises attractiveness of the sea port.

4. Overview of the Link Between Seaport Attractiveness and State Competitiveness Advantages

Expected to illustrate the present situation in Baltic sea ports, the ports of Estonia, Latvia and Lithuania are compared with number of European leading seaports (Hamburg, Antwerpen, Rotterdam). Port performance will be

analyzed trought the port technical parameters, turnover and financial indicators. The players in the eastern coast of Baltic sea regional market are ports of Russian Federation – 65% of cargo turnover in the region (turnover in 2017 is 247,48 mln. t), Latvia – 16% (60,29 mln. t), Lithuania – 14% (52,97 mln. t) and Estonia – 5% (19,2 mln. t). It can be highlighted that the shipping alliance 2M activity in Baltic sea attracted new competitors – polish seaports from the southern coast region (Fig. 4).

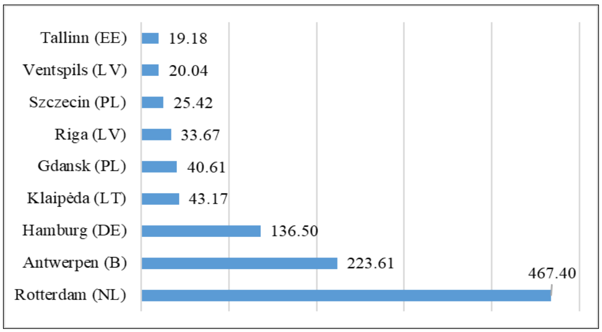


Fig. 2 The turnover of seaports in 2017, mio t [20]

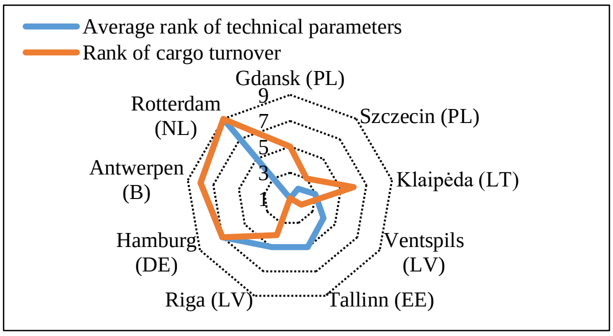


Fig. 5 The rank of turnover and average of rank of ports technical parameters in 2017 [20]

The ranking of the set of the technical parameters of the port (Fig. 5) – depth of port channel (m), territory area (ha), length of the quays (m) – not always leads to the biggest turnover of cargo, the correlation between rank of turnover and technical parameters is week ($k = 0.6$). According to the high rank of port technical parameters it can be assumed that there are the possibilities to develop port activities in Tallinn, Ventspils and Riga. Oposite, there are in comparison better rank of turnover than in technical parameter (may the insufficient level of infrastructure) in ports of Gdansk or Klaipeda.

The analysis of port productivity ranking (Fig. 6) shows, that highest rank of port area, territory, productivity is reached in Klaipeda port, despite, that, productivity of quays length and port workers are very low (rank 2). For analysed ports of eastern and southern region of Baltic sea are characteristic low level of productivity of port workers. Conditionaly ports can be divided into three groups: worldwide leaders Hamburg, Antwerpen and Rotterdam (rank 7-9), region leaders Riga, Klaipėda and Gdansk (rank 4-6) and ports "in transition" – Ventspils, Tallinn, Szczecin (rank 1-3). Ports „in transition" are undergoing changes in cargo flow: Ventspils changing from row oil cargo to the dry bulk (coal), Tallinn – switched to the passengers and ro-ro cargo.

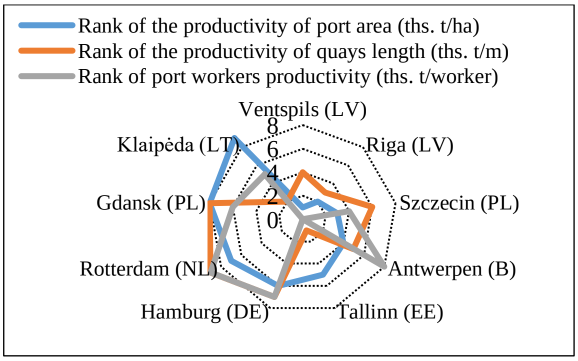


Fig. 6 The rank of productivity of ports in 2017

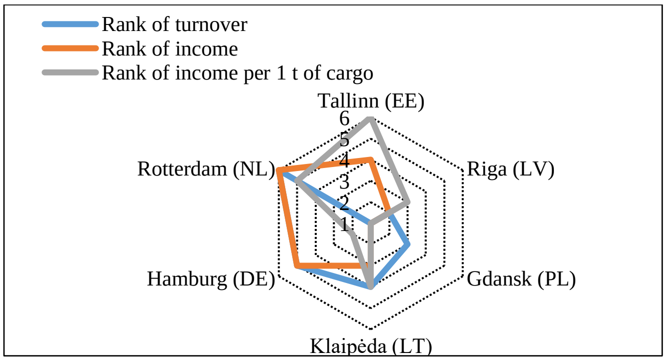


Fig. 7 The rank of turnover and financial indicators in 2017 [21]

The analysis of financial indicators describe different picture (Fig. 7). The port of Tallinn shows best financial results of income per 1 tone of handled cargo in 2017 (rank 6 of 6), port of Hamburg – rank 2. There may be various reasons for it, e.g. port dues and land rent price of ports are inadequate with the low level of income; not certain level of utilization of port infrastructure; high level of port authorities expenditures; not certain level of productivity of technologies of stevedoring companies in the port etc.

Measurement of financial efficiency of ports (Fig. 8) describes possibilities to create added value and proves the motto of leading seaports in Europe: „From tons – to added value". The profitability fixed in Klaipeda seaport authority is the best between valued ports. The low level of financial leverage (lowest rank stated for the Klaipeda and Gdansk) and it is discussed by economists, because small number of leverage can be provided by low level of external investment of port or show hight level of accumulated unused working capital, on the other hand, high level of leverage shows the appropriate level of financial risk. Indicator of return on equity ROE (best fixed in port of Tallinn and Gdansk) describe level of utilisation of port infrastructure and is useful for comparing the profitability with others.

According to the World economic forum grouping, economies of Latvia and Lithuania are in transition from stage 2 to 3, Estonia – in stage 3, innovation-driven economies group. The competitiveness of infrastructure of Baltic States is influenced by the infrastructure of the port (Fig. 9). The competitiveness of quality of roads and railways infrastructure of Lithuania is in higher position than other Baltic states, but the competitiveness of port infrastructure is at the lowest

position. Planned to build external deep-sea port in Lithuania likely increase the competitiveness of port and country infrastructure and might improve seaport performance and employment ratio, reduce social exclusion, but there is a danger of increasing pollution of the environment and separation of the seaside and the territory of the other country.

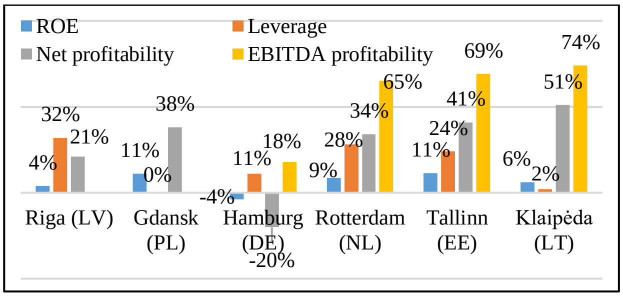


Fig. 8 Financial efficiency of ports in 2017 [21]

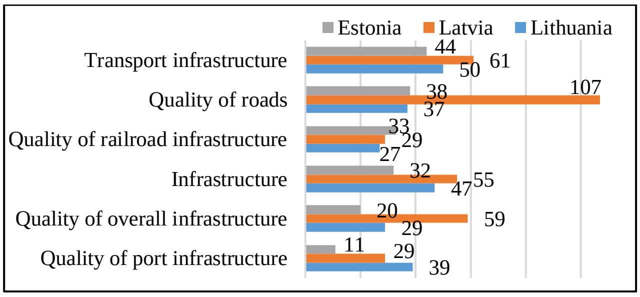


Fig. 9 Infrastructure competitiveness index 2017, n/137) [22]

Analysis the Eurostat (2018) data of 2014-2017 [23] shows, that indicators of Lithuania in social exclusion, poverty and income inequality are distinguished by negative trends with a rising trend: the share of persons in the area of social exclusion and poverty in increased by 3%, while in Estonia it decreased by 3%, in Latvia it increased by 0.2%; the inequality income distribution indicator in Lithuania remains of the second largest in the EU – 7.5, indicator of Estonia 5.6, in Latvia 6.2 and it's characterized by a consistent downward trend. The part of the population by the low intensity of work, in Lithuania is more than 10%, in Latvia by 7%, in Estonia less than 6%, the proportion of people who suffer from external noise in 2012-2016 Lithuania and Latvia are more than 13% (Estonia 10%). The change in the indicator is due to the consistent development of national, EU and international environmental maritime transport.

To summing up, the port attractiveness can be explained as the port competitiveness and its sustainability have impact to the formation of the country's competitiveness advantages. And the hipothetical model of countries competitive advantage links on port performance can be proposed (Fig. 10).

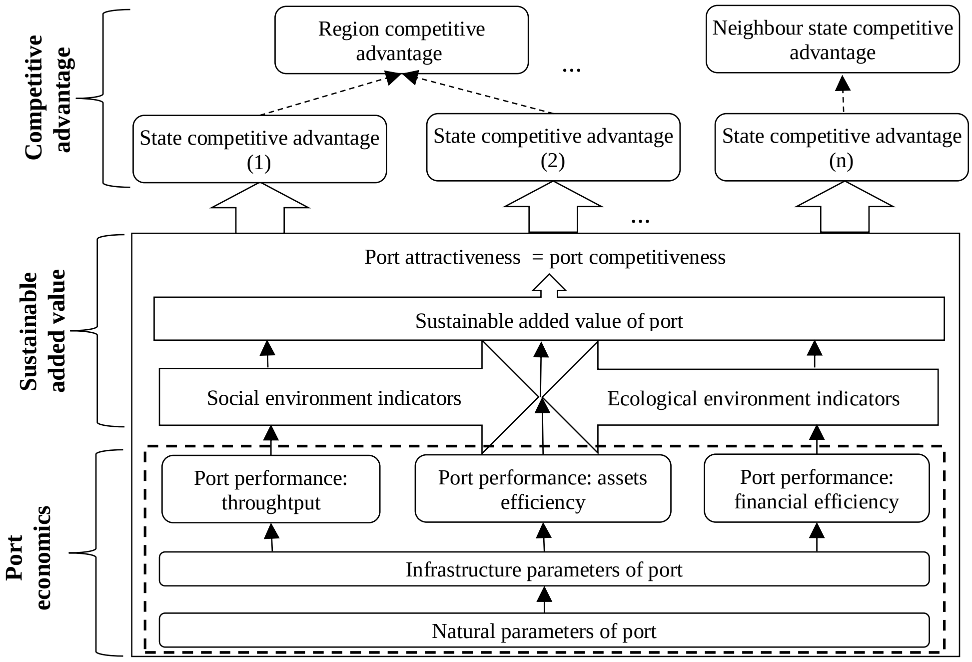


Fig. 10 The model of countries competitive advantage links on port performance

Effective operation of the Baltic ports is likely to have a positive impact on the indicators of the social and ecological environment, but examples of nowdays social indicators form the opposite of the theoretical view. The social indicators of Baltic States are different and it is difficult to establish a direct link between state's strategic sector, seaport, development, and socio-economic development and quality of life.

5. Conclusions

The effective state-owned seaport governance idea could be described on the basis of sustainable governance model, including four-dimensional management model idea integrated within the national logistical connectivity conception because the widening of set of internal and external parameters in the context of ambiguity, emergency and dynamics of global supply chain environment. Theoretical background of effective governance principles identified the

strong relation between state-owned seaport governance model and seaport attractiveness for the wide set of stakeholders and such type of justification summarized that the principles of sustainable governance modelling could be applied. The sustainable governance modelling is based on the complex system, ecosystem theories fulfilled by the main principles of new public governance and governance orientation to the extended added value creation. These theoretical assumptions and findings create possibilities to analyze state-owned seaport governance problem as the problem of value networks governance modelling where geographical, political, economic, technological, and social indicators of seaport activity could be compared in the context of national competitiveness. In this context the comparison of different models of seaport governances and seaport attractiveness could be expressed through this set of indicators: seaport productivity and volumes, efficiency and performance, logistical connectivity, social added value indicators which are main national competitiveness advantages.

References

1. **Rainey, H.G.; Steinbauer, P.** 1999. Galloping elephants: developing elements of a theory of effective government organizations, Journal of Public Administration Research Theory 9(1): 1-32.
2. **de Langen, P.W.** 2015. Governance in seaport clusters. In Haralambides, H. E. (Ed.). Port management, New York: Palgrave Macmilan.
3. **Mickienė, R.; Valionienė, E.** 2018. Substantiation of value oriented management changes of state seaport, Social Research 41(1): 25-40.
4. **Ibrahimi, K.** 2017. A theoretical framework for conceptualizing seaports as institutional and operational clusters, Transportation Research Procedia 25: 261-278.
5. **Upward, A.; Jones, P.** 2016. An ontology for strongly sustainable business models: defining an enterprise framework compatible with natural and social science, Organization & Environment 29(1): 97-123.
6. **Bocken, N.; Short, S.; Padmakshi, R.; Evans, S.** 2013. A value mapping tool for sustainable business modelling, corporate governance, The International Journal of Business in Society 13(5): 482-497.
7. **Joyce, A.; Paquin, R.L.** 2016. The triple layered business model canvas: a tool to design more sustainable business models, Journal of Cleaner Production 135: 1474-1486.
8. **Parrish, B.** 2010. Sustainability-driven entrepreneurship: principles of organization design, Journal of Business Venturing, 25(5): 510-523.
9. **Breuer, H.; Lüdeke-Freund, F.** 2017. Values-Based Network and Business Model In-novation, International Journal of Innovation Management 21(3): 1-35.
10. **Tiemann, I.; Fichter, K.** 2016. Developing business models with the sustainable business canvas: manual for conducting workshops. Oldenburg and Berlin [online cit.: 2018-05-31]. Available from: https://www.borderstep.de/wp-content/uploads/2016/10/Tiemann-Fichter-Workshopkonzept-EN-RZ2.pdf
11. **Cann, O.** What exactly is economic competitiveness? [online cit.: 2017-09-27]. Available from: https://www.weforum.org/agenda /2017/09/what-is-economic-competitiveness
12. **Porter, M.E., Ketels, C., Delgado, M**. 2007. The Microeconomic Foundations of Prosperity in The Global Competitiveness Report 2007-2008 (2007), World Economic Forum, p. 51-80.
13. **Stiglitz, J.E., Sen, A., Fitoussi, J.P** 2010. Report by the Commission on the Measurement of Economic Performance and Social Progress. [online cit.: 2018-05-31]. Available from: http://www.insee.fr/fr/publications-et-services/dossiers_web/stiglitz/doc-commission/RAPPORT_anglais.pdf
14. **Faber, M.** 2008. How to be an ecological economist, Ecological Economics 66(1):1-7.
15. **Figge, F., Hahn, T.** 2004. Sustainable value added-measuring corporate contributions to sustainability beyond eco-efficiency, Ecological Economics 48(2): 173-187.
16. **Bakari, M.E.K.** 2017. The Dilemma of Sustainability in the Age of Globalization: A Quest for a Paradigm of Development, NY: Lexington Books.
17. **Porter, M.E.** 1990. The Competitive Advantage of Nations, Basingstoke, New York: PalgraveMacMillan.
18. **Schwab, K.** 2017. Ketvirtoji pramonės revoliucija, Vilnius: Vaga.
19. Logistics Property and Infrastructure, [online cit.: 2018-05-31]. Available from: https://toplink.weforum.org/knowledge/insight/a1Gb0000000pTDoEAM/explore/dimension/a1Gb0000005QyaKEAS/summary. Mapping Global Transformations. World Economic Forum.
20. **Qiu, X., Wong, E.Y.C, Lam, J. S. L.** 2018. Evaluating economic and environmental value of liner vessel sharing along the maritime silk road, Maritime Policy & Management, 45(3): 336-350.
21. Seaports Authorities Statistics. 2018.
22. Seaport Authorities Annual reports. 2017.
23. The Global Competitiveness Report 2017-2018. [online cit.: 2018-06-20]. Available from: http://www3.weforum.org/docs/GCR2017-2018/05FullReport/TheGlobalCompetitivenessReport2017%E2%80%932018.pdf
24. Eurostat (2018). [online cit.: 2018-06-20]. Available from: Inequality of income distribution: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsdsc260; People at risk of poverty or social exclusion: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode= t2020_50; People living in households with very low work intensity: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=t2020_51; Proportion of population <…> they suffer from noise: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin= 1&language=en&pcode=tsdph390

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Economy of Incorporating Buffer Time into Airline Schedule

D. Liptakova[1], S. Kis[2], Z. Susterova[3]

[1]*Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Slovakia,*
E-mail: dorota.liptakova@tuke.sk
[2]*Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Slovakia,*
E-mail: slavomir.kis@tuke.sk
[3]*Technical University of Kosice, Faculty of Aeronautics, Rampova 7, 041 21 Kosice, Slovakia,*
E-mail: zuzana.susterova@tuke.sk

Abstract

The article deals with the question of economic feasibility of adding slack time into airline schedule buffer. The terms of strategic and tactical delay will be explained emphasizing the difference between the origin of these operational discrepancies. Basic calculations for the costs of these delays will enable us to discuss the reasonableness of adding buffer to scheduled airline services.
KEY WORDS: *airline schedule, buffer time, delay, slack time*

1. Introduction

Airline scheduling is a time demanding process that begins several months to years before the actual flight and requires the cooperation of airline staff across different departments [1]. Account must be taken of a number of internal as well as external factors, including passenger preferences, airport operating hours, or flight schedules of affiliated carriers [2]. Nonetheless, these plans are regularly disturbed by irregularities that may lead to deviations from normal operation on the scale from small delays or deviations from routine procedures to significant delays to flight cancellations and redirection of available resources in order to return the flight schedule to its original state.

The most frequent manifestations of the irregular operation of the air carrier are delays [3]. It is in their best interest to minimize the occurrence of delays as the market share of the carrier is positively correlated with on-time airline performance [4]. Carriers have different strategies available to answer the delay. In our article we aim to discuss one of the pro-active strategies of robust planning, namely addition of buffer times into the flight timetable. However, as buffer times are form of strategic delay, it is necessary to take a closer look at the feasibility of buffer times and test their impact on carrier performance.

2. Methods and Materials

In order to examine the possibility of adding buffering times to flight schedules, it is first of all necessary to understand the concept of buffer times and the reasons why the addition of buffer times is not necessarily beneficial, although they serve to mitigate the consequences after the occurrence of delays.

Subsequently, we created an application to generate flight schedules and delays, through which we examined the effect of embedding buffer times in the flight schedule on fleet performance. Our analysis is presented in this article.

3. Definition of Schedule Buffer in Connection with Delay

A delay in aviation could be determined by measuring and tracking multiple time data related to each flight phase. However, the most frequently delay is measured as the deviation from aircraft roll start and end times (off-block and on-block), which are presented to the public as the departure and arrival times and are the most consistent data in the flight timetable, independent of the type of aircraft or the nature of the flight. Based on this delay data, airline punctuality is monitored by airlines, airports, travelers, international organizations, or commercial companies providing operational statistics. To monitor the performance of the air traffic services and air traffic management system, deviations from the time of the last filed flight plan are observed [5].

We can also look at the delays from multiple perspectives. We recognize tactical delays (operational) and strategic delays [6].

We talk about the tactical (operational) delay on the day of the operation. The immediate deviation from planned operation will require reactionary measures to eliminate this primary tactical delay. Due to the interconnection of different schedules for aircraft, crew and passengers [7], as well as the fact that the same aircraft and crew serve several consecutive flights, one flight delay can trigger an avalanche effect and affect a number of other flights. In such case we talk about reactionary tactical delay.

If delays occur on certain city pair more often they can be tracked and evaluated. The reasons for the delay, its

consequences and the need for countermeasures are monitored [8]. In the next planning period, it is possible to incorporate countermeasures for the identified delay into the new timetable and adapt it accordingly, for example by extending the expected duration of some phases of flight or by adding buffer time. We are talking about strategic delays. This delay is in fact a precautionary measure that serves to improve the flight schedule at the level of the punctuality indicator of the airlines. This measure may concern only individual, selected flights. When considering adding a strategic delay to a given flight, the planning department must carefully consider possible costs that arise, for example, by prolonging the crew's duty time. However, strategic delays may also affect the entire airline network. At the cost of increased punctuality, passengers may lose the opportunity to switch to certain lines. Aircraft also spend less time in the air, which reduces their effectiveness. The above mentioned levels of carrier's flight delays are shown in Table 1.

Table 1

Delay levels in airline operations

delay level	tactical delay	strategic level
gate-to-gate level	primary delay of a single flight caused by operational deviation	adding buffers into schedule
network level	reactionary delay of consecutive flights caused by primary delay	increasing punctuality of schedule at the expense of lower effectiveness of the fleet, higher costs

In order to complete the introduction into the subject of airline delays and schedule creation it is necessary to define the term "buffer time". Many variations of this term can be identified in literature, among them slack [9] or slack time [10]. This element forms a solid part of the procedures for reducing the occurrence of irregularities. Consideration of buffer insertion is a regular part of the schedule planning process and is applied either for the flight preparation phase between two legs, or for the phase of actual flight that can be scheduled with a certain time margin.

Schedule slack time is a form of strategic delay. It is a predefined amount of time that is inserted into the schedule when it is planned and which serves as a bumper. In the event of a tactical delay, the buffer time can absorb part of or whole delays, and the next phase of flight can be initiated as planned [11].

Air carriers can use buffer times for two reasons:

1. they improve predictability and operation planning as they absorb delays and
2. they improve punctuality.

On the one hand, this tactics helps carriers maintain effective operation while at the same time allowing them to increase their market share, especially in the higher revenue segment of business travelers, who prefer punctuality to the price of a ticket when choosing a carrier. Many carriers consider reducing delays as their strategic goal because it is one of the carrier's quality indicators in the eyes of the traveling public.

At the same time, however, adding buffer time also proposes possible losses. Consideration should be given to the justification and length of buffer times. When analyzing the consequences of delays from a financial point of view, the additional costs incurred to the carrier or to passengers are often examined. However, it is also necessary to perceive the costs associated with damping possible delays by adding buffer time. The aim should be to achieve a balance between these costs, that is the cost of using buffer times should be equal to the expected cost of delays.

4. Basic Properties of a Created Application

In order to test different scenarios for incorporating buffer times into aircraft schedule, we created an application to generate schedules and delays. We set a rule to generate a schedule for 6,000 aircraft. Depending on the set amount of time spent in the air and whether buffer times (hereinafter BT) were used the final schedule for 6,000 aircraft included approximately 23,000 to 32,000 flight legs during 24-hour operation, which corresponds to the number of flights operated on a daily basis by Eurocontrol. [12] [13]

We gradually generated 4 sets of flight schedules (hereinafter SCH):

- SCH without BT;
- SCH treated with BT during the whole daytime operation;
- SCH treated with BT once daily during mid-day;
- SCH treated with BT twice a day, in the morning and afternoon hours.

During analysis we observed several variables:

- the number of legs generated for each scenario;
- the number of effective minutes in the air – we calculated only the planned flight times before the addition of the buffer time. This allows us to monitor how the additional time to the flight schedule would affect the net amount of time spent by aircraft in the air, generating revenue for the carrier;
- delay depth – if delays occur due to an irregularity in the flight timetable, but operation continues without change, delays may propagate in subsequent segments. This delay is called reactionary. Delay depth for individual aircraft was calculated as the sum of the segments that were affected by the reactionary delay.

5. Essential Analysis of Outputs for Individual Aircraft

Based on the set rules for generating flight schedules with different additions of buffer times, we generated four sets of flight schedules. Table 2 gives an overview of the average values of the monitored variables for each scenario.

Table 2

Outputs from generated flight schedules

	SCH without BT	SCH with BT during H24	SCH with BT once a day	SCH with BT twice a day
Nr. of legs	28,016	26,823	27,933	27,756
Avg. Nr. of legs	4.6693	4.4705	4.6555	4.6260
Change in %	ref. value	-4.26	-0.30	-0.93
Effektive minutes in the air	578.59	552.60	577.33	574.76
Change in %	ref. value	-4.49	-0.22	-0.66
Avg. delay depth	0.88	0.03	0.76	0.68
Change in %	ref. value	-96.59	-13.64	-22.73

As expected, the addition of buffer times influenced the number of flights that can be generated during 24-hour operation. Every block of buffer time added to the flight schedule eventually reduces the length of the day, during which we can plan further flights. In Table 2 and also Figure 1 we can observe a significant difference between the number of legs in flight schedule generated without and with buffer times added to each and every flight. For untreated schedules the application generated for 6,000 aircraft an average number of 28,016 flights. When each flight was treated with blocks of buffer time the average number of flights for 24-hour operation was 26,823.

A similar difference to the total number of flights is seen in the efficient use of aircraft. The airplanes spend an average of 578.59 minutes in the airplane in case their schedules were not treated with buffers. Schedules where one block of buffer time was added had an average effective aircraft utilization of 577.33 minutes. For schedules with 2 blocks of buffer time, the average daily effective use dropped to 574.76 minutes. Again, the most striking difference is evident in the schedule where all flights were treated with blocks of buffer time. For these cases, the application generated schedules with an average effective utilization of 552.6 minutes.

Another analyzed output is the delay depth. For schedules without buffer time, the average delay depth was 0.88. For the flight schedules with buffer time inserted in the afternoon, the average depth of delays decreased by more than 13% to 0.76. Where the schedule was treated with buffer time in the morning and afternoon, the average depth of delays decreased by more than 22% to 0.68. In the case of flight schedules, where each section was treated with buffer time, the propagated, reactionary delay was almost unexpected (see Fig. 2).

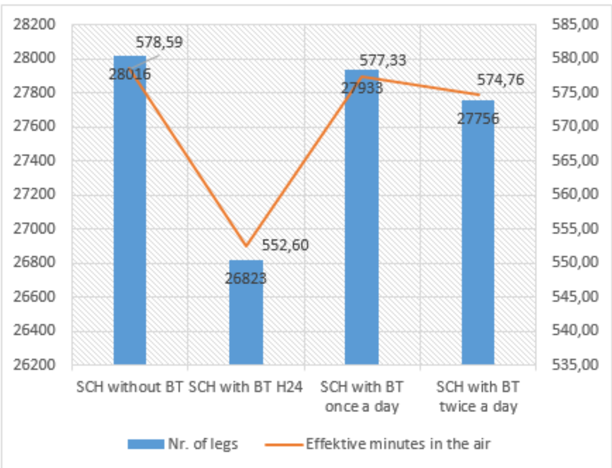


Fig. 1 Outputs from generated flight schedules for different scenarios

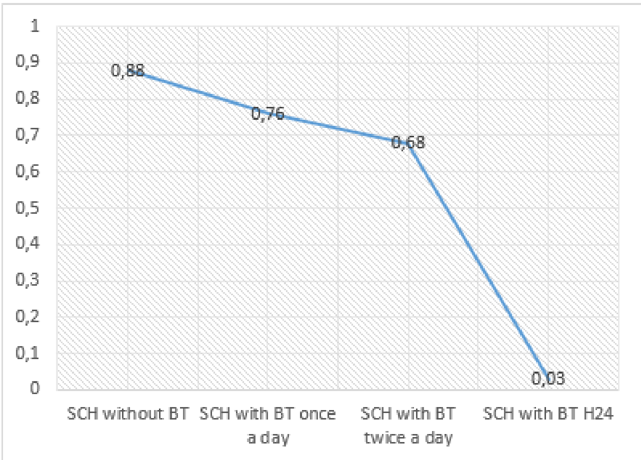


Fig. 2 Delay depth for different scenario schedules

6. Economic Impacts of Delays

The Federal Aviation Authority (FAA) has commissioned a collective of colleges and institutes to study the impact of delays on the US economy. While previous studies have mainly focused on assessing the costs of delays for air carriers, Nextor study has also focused on the costs of delays for passengers, as well as quantifying the impact on the nation's economy as a whole. The study published at the end of 2010 handles data from 2007 [14]. According to the results of the research, the costs of the airline industry amount to $.32.9 billion annually due to irregularities. Of this

amount, $8.3 billions are the costs to be carried by the airlines. Another $3.9 billion are expenditures that are carried by the whole public, respectively state, and stems from the transfer of passengers from aviation to road transportation, where increased costs are incurred, for example, for road maintenance or the costs of greater air pollution by motorists. Similarly $4 billion are incurred to the public as a result of the loss of gross domestic product, as the Nextor study has shown a strong correlation between the country's economic performance and the growth of air travel delays in the United States. However, the most outstanding output are the costs carried by the passengers, as they were estimated at $16.7 billion. Costs to passengers were incurred because the resulting delays caused an economic loss to them [14].

Although there is no such extensive study available for the European area according to our knowledge, it is worth mentioning another study that arose at the University of Westminster and was developed for Eurocontrol [15]. The authors of the study seek to quantify the cost of delays for airlines, addressing both tactical and strategic delays. In their calculations they chose to omit delays of less than 15 minutes duration. For 1 minute of tactical delay, the average cost for the carrier was estimated at €74. The study calculated the average cost per one minute of strategic delay at €15, and in case this strategic delay was used the average cost was €22. However, this study is quite old. The prices of the item prices on the basis of which the costs were calculated have changed over time, they mostly increased. The 2011 Eurocontrol Performance Report has already adjusted the prices to 79€ per 1 minute of tactical delay and 27€ per 1 minute of strategic delay without. The costs for utilized strategic delay were not given in the report [16].

If we can determine the value of the cost of buffer time and delays for the carrier, then we can calculate the amount of flights that should be delayed in order to make sense of the applied buffer times. For the calculation, we will use the relationship for strategic and tactical delays as reported in the Westminster University study [15]. We will look for the variable x, which will represent the ratio of the aircraft delayed by more than 15 minutes, in accordance with the study. For the calculation, we need the following relationship (1).

$$22x + 15\,(1 - x) < 74x. \tag{1}$$

After calculating the inequality, we obtain a result of $x > 0.22$. This means that adding buffer minutes to the flight schedule will be economically effective provided that more than 22% of flights will be delayed by more than 15 minutes.

7. Conclusions

Examining different scheduling scenarios, adding buffer times to flight schedules brings both advantages and disadvantages. Added blocks of buffer time obviously led to a reduced spread of delay in carrier network. For the flight schedule treated with buffers during the whole day of operation only rare cases of reactionary delay occurred, otherwise the delay was isolated. On the other hand, the addition of time buffers caused a reduction in fleet efficiency when the effective time of aircraft utilization with all day buffer treatment fell by 4.49%.

Using the above-mentioned values, we can calculate that the drop in fleet utilization by 4.26%, which is the difference in the daily number of flights performed in the non-buffer schedule and with all-day buffering, would entail a fall in revenue by about €300 for one aircraft per day [17, 18]. However, this value is not final. A further decline in revenue could be due to the switch of passengers to competition. Especially on city-pairs where several carriers offer services, the addition of buffer time to the flight schedule could deter passengers by gaining the impression that a competing carrier can provide the same service at a similar price level with a shorter duration of flight [19]. Addition of buffer times into the schedule also entails additional costs, but they are absorbed in operating costs and can be difficult to quantify [20].

On the other hand, however, the carrier is able to ensure that the flight schedule is more robust and does not subject to delaying easily. By this the carrier can build a brand of trustworthy partner and focus on a segment of higher revenue customers [21]. This would compensate for the loss resulting from lower effective aircraft utilization and higher operating costs.

The created application for generating schedules and delays has certain limitations in use. The presented results can not be related to any type of aircraft and market. However, the results from the application can be generalized and the statement can be formulated that the use of buffer times can greatly mitigate the impact of delays not only on particular flights but also on the subsequent planned flights for the given aircraft, thus minimizing the consequences of delays in the carrier network. At the same time, added buffer times will limit the effective time of aircraft use by only a few percent.

However, the buffer times themselves represent a form of delay and are naturally associated with costs that are difficult to quantify as they are incorporated into the unit cost of passenger transport. Therefore, the decision to apply buffer times by airline requires a detailed economic analysis.

References

1. **Ball, M.O., et al.** 2007. Chapter 1 Air Transportation: Irregular Operations and Control. In: Handbooks in Operations Research and Management Science. Volume 14, Issue C (2007), pp. 1-67. ISSN 0927-0507.
2. **Wensveen, J.G.** 2011. Air Transportation: A management perspective, 7th edition. Farnham: Ashgate. 571 p. ISBN 978-1-4094-3063-6.

3. **Dadpay, A.** 2018. Using a generalized model for air traffic delay: An application of information based duration analysis, Journal of Air Transport Management 67: 153-156. ISSN 0969-6997.
4. **Suzuki, Y.** 2000. The relationship between on-time performance and airline market share: a new approach, Transport. Res. Part E. 36: 139-154.
5. European Commision. 2015. Delays to air transport in Europe: Methods of measuring, reporting and analysing – Final Report of Task Force [online cit.: 2018-03-28]. Available from: <https://ec.europa.eu/transport/sites/transport/files/modes/air/airports/doc/tf2_final_report.pdf>
6. **Cook, A.J.; Tanner, G.; Anderson, S.** 2004. Evaluating the true cost to airlines of one minute of airborne or ground delay: final report [online cit.: 2014-08-21]. Available from: http://westminsterresearch.wmin.ac.uk/17/
7. **Grandeau, S.C.** 1995. The process of airline operational control: diploma thesis. Cambridge: Massachusetts Institute of Technology. 98 p.
8. **Yan, C.; Vaze, V.; Barnhart, C.** 2018. Airline-driven ground delay programs: A benefits assessment. Transportation Research Part C 89: 268-288. ISSN 0968-090X.
9. **Dorndorf, U.; et al.** 2007. Disruption management in flight gate scheduling, Statistica Neerlandica 61(1): 92-114.
10. **Abdelghany, A.; Abdelghany, K.** 2009. Modeling applications in the airline industry. Farnham: Ashgate. 277 p. ISBN 978-0-7546-7874-8.
11. **Ahmadbeygi, S.; Cohn, A.; Lapp, M.** 2010. Decreasing airline delay propagation by re-allocating scheduled slack, IIE Transactions (Institute of Industrial Engineers) 42(7): 478-489. ISSN 0740-817X.
12. Performance Review Report. 2017. An Assessment of Air Traffic Management in Europe during the Calendar Year 2016 [online cit. 2018-01-21]. Available from: http://www.eurocontrol.int/news/performance-review-report-2016
13. NOP Network Operations Portal. 2018. [online cit. 2018-04-01]. Available from: https://www.public.nm.eurocontrol.int/PUBPORTAL/gateway/spec/index.html
14. NEXTOR. 2010. Total Delay Impact Study [online cit. 2013-09-15]. Available from: <www.nextor.org>
15. **Cook, A.J.; Tanner, G.; Anderson, S.** 2004. Evaluating the true cost to airlines of one minute of airborne or ground delay: final report [online cit. 2014-08-21]. Available from: <http://westminsterresearch.wmin.ac.uk/17/>
16. EUROCONTROL. 2011. Performance Review Report : An Assessment of Air Traffic Management in Europe during the Calendar Year 2011 [online cit. 2018-01-10]. Available from: <https://www.eurocontrol.int/sites/default/files/publication/files/prr-2011.pdf>
17. **Kyparisis, G.J.; Koulamas, C.** 2018. Optimal pricing and seat allocation for a two-cabin airline revenue management problem. International Journal of Production Economics 201: 18-25. ISSN 0925-5273.
18. IATA. 2017. Strong Airline Profitability Continues in 2018. [online cit. 2018-02-20]. Available from: <http://www.iata.org/pressroom/pr/Pages/2017-12-05-01.aspx>
19. **Vagner, J.; Jencova, E.; Sekelova, M.; Mizenkova, Z.** 2015. Airline Marketing Options. In: MMK 2015. Hradec Kralove : Magnanimitas, 2015. s. 389-394. ISBN 978-80-87952-12-2.
20. **Baranova, V.; Tobisova, A.** 2012. In: Acta Avionica, 14(24): 70-74. ISSN 1335-9479.
21. **Susterova, Z.; Hanak, P.; Cekanova, D.** 2017. The most recent strategies used by aeronautical companies within the revenue management. In: Aeronautika 17. Lublin : University College of Enterprise and Administration, 2017 P. 100-104. ISBN 978-83-60617-49-6.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Aircraft Velocity Determination Using GLONASS Data

J. Kozuba[1], K. Krasuski[2]

[1]*Silesian University of Technology, Krasińskiego 13 Street; The Faculty of Transport, Poland, Poland, E-mail: aabuzok@wp.pl*
[2]*Polish Air Force Academy, 35 Dywizjonu 303 Street; The Faculty of Aviation, Poland, E-mail: kk_deblin@wp.pl*

Abstract
In the article, the velocity of the Cessna 172 aircraft was determined during an in-flight test conducted around the EPDE military airport in Dęblin, Poland. The velocity parameter was determined on the basis of the aircraft motion dynamics equations in the GNSS navigation system. Target parameters of the Cessna 172 in-flight velocity along the particular axes of the XYZ geocentric frame were determined based on the navigation solution in the GLONASS satellite system. Numerical calculations concerning the Cessna 172 aircraft velocity were performed in the RTKLIB (RTKPOST module) program package The maximum values of the in-flight velocity components (Vx, Vy, Vz) for the Cessna 172 aircraft do not exceed the level of ± 62 m/s. Moreover, the resultant value of the total in-flight velocity of the Cessna 172 does not exceed the level of 75 m/s. The work has also brought up the problem of reliability of determining the in-flight velocity of the Cessna 172 aircraft from the GLONASS solution against the background of the readings from the GPS sensor.
KEY WORDS: *GPS, GLONASS, velocity, aviation test, aircraft*

1. Introduction

The GNSS satellite technology is an indispensable part of the aircraft's technical infrastructure. In particular, the GNSS satellite technology is used in precise air navigation. The primary products of GNSS applications in aviation are position, time, orientation, and velocity. The position parameter is determined by means of the aircraft coordinates in the XYZ geocentric frame, the BLh ellipsoidal frame, or the ENU local frame. The time parameter allows for precise definition of the moment of determining the aircraft position during the ongoing air operation. The orientation parameter makes it possible to reflect the position of the aircraft in terms of HPR (Heading, Pitch, Roll) angles in 3D space. The velocity parameter allows the determination of the changes in the aircraft coordinates as a function of the observation time [1]. The unit of the position parameter is 1m, the unit of time is 1 s, the unit of orientation is 1 degree or 1 radian, and, finally, the unit of velocity is 1m/s or 1kph.

The aircraft velocity parameter was determined in several in-flight tests, as presented in the examples from the research literature:

- in work [2], the accuracy of the Cessna 172 aircraft velocity was determined in the geocentric XYZ frame. The test flight was performed in 2011 at the airport in Mielec, Poland. The velocity of the Cessna 172 was determined using the Doppler effect. The velocity error along the X axis was between 1.3 and 4.3 m/s, along the Y axis between 1.4 and 4.3m/s, and along the Z axis between 1.5 and 3.4 m/s, respectively. In the article, the resultant error of the velocity parameter in 3D space was also specified. The value of that error was from 2.4 to 6.9 m/s.

- in work [3], an attempt was made to determine the velocity of a Cessna 172 aircraft during an in-flight test in Dęblin, Poland (June 1, 2010). Within the scope of the research conducted, the relative velocity of the Cessna 172 aircraft was determined in the local ENU frame as well as the total in-flight velocity. The velocity along the E axis ranges from -30.01 m/s to 31.35 m/s, with an average value being approximately 11.85 m/s. The velocity along the N axis ranges from -37.89 m/s to +31.07m/s, with an average value being approximately 12.13 m/s. The velocity along the U axis ranges from -5.14 m/s to +8.29m/s, with an average value being approximately 0.52 m/s. The total velocity of the Cessna 172 motion is from 0.02 m/s to 37.91 m/s, with an average value being equal to 19.57 m/s.

- in work [4] the velocity of the HALO aircraft was determined during an in-flight test in Germany in 2012. Two receivers, AIR5 and AIR6, were installed onboard the HALO aircraft in order to collect GNSS kinematic observations. Two GNSS reference stations, REF6 and RENO, were also used in the calculation of the aircraft velocity. Along the N axis, the velocity of the HALO aircraft was from -200 m/s to +200 m/s. Along the E axis, on the other hand, the velocity of the HALO aircraft was from -150 m/s to +180 m/s. Along the U axis, in turn, the velocity of the HALO aircraft was from -20 m/s to +20 m/s. The difference of the HALO aircraft velocity between the readings from the AIR5 and AIR6 receivers was, respectively, from -2 m/s to +2 m/s for the N axis, from -2 m/s to +2 m/s for E, and from -0.5 m/s to +0.5 m/s for U.

- in work [5] the velocity of the TS-11 Iskra aircraft was determined during the Deblin’2001 in-flight experiment performed within the "DUNAJ" project. An Ashtech Z-Surveyor geodesic receiver was mounted onboard the TS-11 Iskra aircraft in order to determine its basic navigation parameters. The flight altitude was between 4250 m and almost 7200 m. Moreover, the target in-flight velocity of the TS-11 Iskra aircraft was between 420 kph and almost 480 kph. The position of the aircraft and its velocity were determined on the basis of the RTK-OTF differential method

in the post-processing mode using GNSS base stations.

- in work [6] the velocity of the TS-11 Iskra aircraft was determined during the in-flight experiment performed in 2016 around the EPDE military airport in Dęblin, Poland. Six electronic watches with integral GNSS satellite receiver units were mounted onboard the Ts-11 Iskra aircraft. This made it possible to verify the suitability of electronic watches with integral GNSS receivers for aeronautical applications. Flight altitude started from 1000 m and the in-flight velocity reached the 400 kph level.
- in work [7] the velocity of the Robin DR400-140B aircraft was determined during the in-flight experiment performed in Spain in the early spring of 2009. The VFR flight was performed in the morning, local time. Navigation parameter values were collected with a dual-frequency receiver, Septentrio PolaRx2, mounted onboard the aircraft. The velocity of the Robin DR400-140B aircraft was determined using the EVA method and the modified Kennedy method. The in-flight velocity difference between the two test methods in the ENU local frame was up to ±0.04 m/s.
- in work [8] the velocity of an aircraft was determined on the basis of the GNSS and INS sensors in the ENU local frame. During the test flight, the altitude of the aircraft ranged from 100m to almost 600 m. On the basis of a velocity comparison between the GNSS and INS sensors, the maximum standard deviation is 11.2 cm/s. Furthermore, the maximum RMS error of the velocity difference between the readings from the GNSS and INS sensors is 14.4 cm/s.
- in work [9] aircraft velocity and flight dynamics were determined on the basis of GPS absolute positioning and DGPS differential positioning. Flight velocity accuracy for horizontal coordinates was approximately 2-4 mm/s on the basis of comparing the results obtained from GPS absolute positioning and DGPS differential positioning. Flight velocity accuracy for the vertical coordinate was approximately 29.7 mm/s on the basis of comparing the results obtained from GPS absolute positioning and DGPS differential positioning.

In the article, the velocity of the Cessna 172 aircraft was determined using the GNSS satellite technique. The velocity of the Cessna 172 aircraft was determined using GLONASS observations (SPP method). In the experiment, GLONASS code observations were used which were obtained from a dual frequency Topcon HiperPro receiver installed onboard the Cessna 172 aircraft. The in-flight test was conducted in 2010 around the military airport in Dęblin, Poland. In the article, the comparison was also made between the velocity parameter obtained from the GLONASS and the GPS solution.

2. Mathematical Model of Designation the Aircraft Velocity Based on GLONASS Data

The basic mathematical expression describing the in-flight velocity in the GLONASS satellite navigation system may be written as follows [10]:

$$\begin{cases} Vx = \dfrac{dX}{dt}; \\ Vy = \dfrac{dY}{dt}; \\ Vz = \dfrac{dZ}{dt}, \end{cases} \tag{1}$$

where (Vx, Vy, Vz) - aircraft velocity along the axes of the XYZ geocentric frame; $dX = (X_{i+1} - X_i)$ - coordinate difference along the X axis; $dY = (Y_{i+1} - Y_i)$ - coordinate difference along the Y axis; $dZ = (Z_{i+1} - Z_i)$ - coordinate difference along the Z axis; i - measurement epoch from the previous step; $(i+1)$ - measurement epoch from the next step; dt - observation time interval.

The aircraft coordinates in the XYZ geocentric frame are determined on the basis of the Single Point Positioning (SPP) absolute method in the GLONASS system, as below [11]:

$$l = d + c \cdot (dtr - dts) + Ion + Trop + \mathrm{Re}l + SIFCB_{L1} + RIFCB_{L1} + M_{C/A}, \tag{2}$$

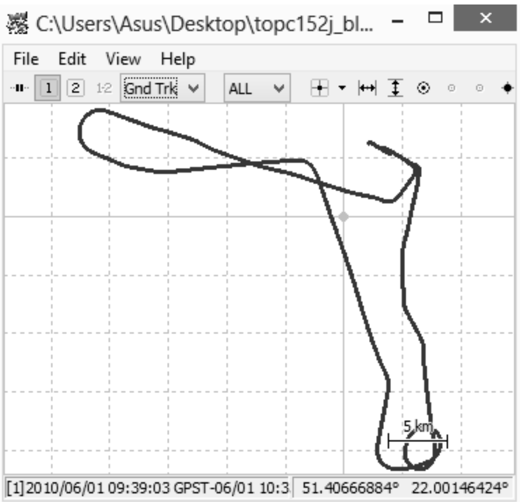
where l - L1-C/A code measurement in the GLONASS system; d - geometric distance between the satellite and the receiver; $d = \sqrt{(Z - X_{GLO})^2 + (Y - Y_{GLO})^2 + (Z - Z_{GLO})^2}$; (x, y, z) - aircraft position in the ECEF geocentric frame; $(X_{GLO}, Y_{GLO}, Z_{GLO})$ - GLONASS satellites coordinates; c - speed of light; dtr - receiver clock bias correction; dts - satellite clock bias correction; Ion - ionosphere delay; $Trop$ - tropospheric delay; $\mathrm{Re}l$ - relativistic effect; $SIFCB_{L1}$ - satellite inter-frequency bias for code measurement at L1 frequency; $RIFCB_{L1}$ - receiver inter-frequency bias for code measurement at L1 frequency; $M_{C/A}$ - measurement noise and multipath effect.

The coordinates of the aircraft (X, Y, Z) determined from Eq. (2) are referred to the ortho-Cartesian XYZ geocentric coordinate frame. The coordinates of the aircraft (X, Y, Z) are determined using the least squares method in

the stochastic process for all recorded measurement epochs within the in-flight experiment.

3. Research Experiment

Within the scope of the article presented, a research experiment was conducted on the use of the GLONASS navigation system in air navigation for aircraft precise positioning. The main objective of the work was to retrieve the velocity of the Cessna 172 aircraft in the XYZ geocentric frame. Code observations and satellite navigation data used in the research test came from the GLONASS system. GLONASS satellite observations and navigation data were recorded with the the Topcon HiperPro geodesic receiver mounted in the cockpit of the Cessna 172. The Cessna 172 aircraft was used in the in-flight experiment conducted at the EPDE military airport in Dęblin, Poland (see Fig.1). The test flight of the Cessna 172 aircraft was performed early before the noon time and lasted approximately one hour. It should be noted that the test flight was conducted for the needs of the research project: "Monitoring System for Aircraft and Vehicles of Public Order Services Based on GNSS" During the test flight, navigation parameters of the Cessna 172 aircraft were recorded in real time and in post-processing mode. During the test flight, the position of the Cessna 172 aircraft was monitored, as well as its navigation parameters such as in-flight velocity and attitude [12]. It should be added that during the Cessna 172 test flight landing approach procedures using the GNSS satellite system were checked and verified. In particular, an NPA GNSS non-precision approach procedure was performed which used GPS and GLONASS satellite systems. In the non-precision GNSS NPA approach procedure, the assumed horizontal aircraft positioning accuracy may be up to 220 m. Moreover, the limit of Horizontal Protection Levels (HPL) for lateral navigation (LNAV) can be up to 556m. It should be noted, however, that there are no accuracy and reliability standards of satellite positioning for vertical navigation (VNAV) in the NPA GNSS procedure. Additionally, in the GNSS NPA procedure the availability of the aircraft positioning navigation solution must exceed 99%. In the GNSS NPA procedure, time to alarm is 10s and the continuity of the navigation solution may not be worse than 10^{-4}/hour [13]. It should be noted that only GPS and GLONASS navigation systems have been allowed by ICAO to be used in civil aviation. Moreover, ABAS, SBAS and GBAS are used in civil aviation to improve the accuracy of aircraft positioning. In the in-flight experiment in Dęblin, the EGNOS system was also used in order to determine the quality parameters of the GNSS satellite positioning within the framework of the SBAS support system in civil aviation. Furthermore, works were carried out on the application of GBAS in civil aviation. The objective of this was to apply the RTK-OTF differential technique to accurately retrieve the flight trajectory of the Cessna 172 aircraft.



Source: Author's own work, developed on the basis of RTKLIB software package

Fig. **Error! No sequence specified.** The Cessna 172 flight trajectory in the horizontal plane

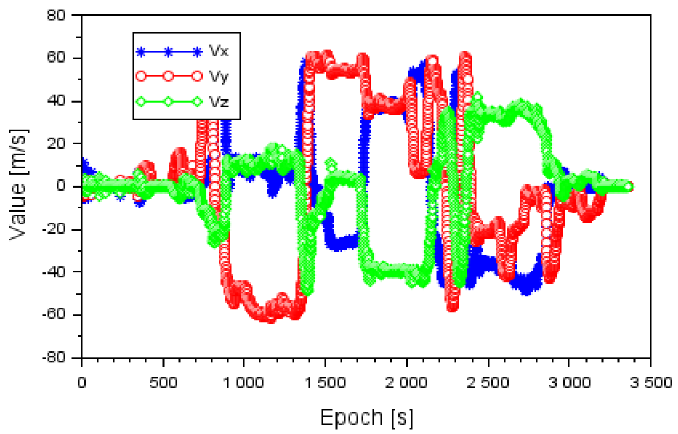
For the purposes of the article, the in-flight velocity of the Cessna 172 aircraft was determined in the XYZ geocentric frame on the basis of the GLONASS solution. Numerical calculations were made using the RTKLIB (RTKPOST module) program For the purposes of the research conducted, the following configuration of the parameters being determined, and models used in the calculations has been set as below [14]:

- GNSS system: GLONASS system;
- GNSS system time: GPS Time;
- observation type: code P1 observations;
- computation type: post processing in RTKLIB software;
- positioning mode: kinematic in RTKLIB software;
- positioning method: SPP method in RTKLIB software;
- GLONASS observations source: RINEX 2.11 file in RTKLIB software;

- method of determining the unknowns parameters: least square estimation in RTKLIB software;
- computation interval: 1s in RTKLIB software;
- observation weighting: applied in RTKLIB software;
- a priori accuracy of the GLONASS code measurements: 1 m in RTKLIB software;
- elevation mask: 5^0 in RTKLIB software;
- instrumental biases DCB P1-C1: applied in RTKLIB software;
- instrumental biases IFCB P1-P2: applied in RTKLIB software;
- relativistic effects: applied in RTKLIB software;
- Sagnac effect: applied in RTKLIB software;
- ephemeral data: broadcast ephemeris in RTKLIB software,
- model of determination the GLONASS satellites coordinates: 4th Runge-Kutta method;
- source of GLONASS satellite clock data: broadcast ephemeris in RTKLIB software;
- ionospheric delay: Klobuchar model in RTKLIB software;
- a priori receiver coordinates: on the basis of RINEX 2.11 observation file in broadcast ephemeris in RTKLIB software;
- troposphere model: Saastamoinen model in RTKLIB software;
- output reference frame of coordinates: XYZ geocentric frame in RTKLIB software;
- multipath effect: not applied;
- unit of aircraft coordinates: 1 m;
- unit of aircraft velocity: 1m/s;
- output reference frame of velocity: (*Vx*, *Vy*, *Vz*) geocentric frame in RTKLIB software.

4. Results and Discussion

Within the scope of the research, three numerical tests were performed in order to determine the in-flight speed of the Cessna 172 aircraft during the flight experiment in Dęblin. In the first test, the in-flight velocity along the particular axes of the XYZ geocentric frame was determined. The values of the velocity parameters (*Vx*, *Vy*, *Vz*) were determined according to the Eq. (1).



Source: Author's own work, developed on the basis of RTKLIB software package

Fig. 2 The velocity parameters of the Cessna 172 aircraft

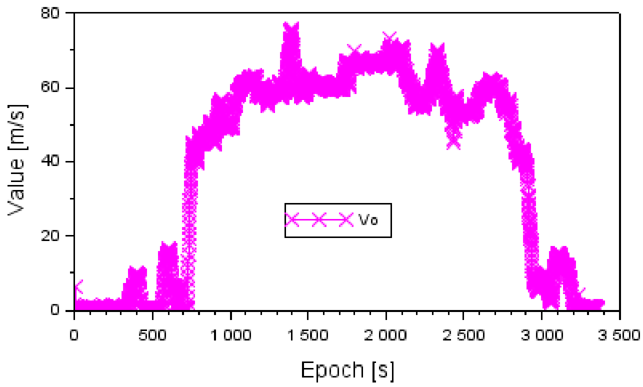
Fig. 1 presents the Cessna 172 aircraft velocity parameter values (*Vx*, *Vy*, *Vz*) on the basis of the GLONASS solution. The *Vx* parameter takes the values from the numerical range of -48.8 m/s to +58.1 m/s. Moreover, the *Vy* parameter takes the values from the numerical range of -61.6 m/s to +61.4 m/s. The *Vz* parameter in turn takes the values from the numerical range from -49.1 m/s to +41.6 m/s. It should be noted that the dispersion of velocity results is the largest for the *Vy* parameter whereas it is the lowest for *Vz*. The difference between the maximum velocity values for *Vy* and *Vz* is approximately +20 m/s. The difference between the maximum velocity values for *Vy* and *Vx* is approximately +3 m/s. The difference between the maximum velocity values for *Vx* and *Vz* is in turn approximately +17 m/s.

In the second in-flight test, the total in-flight velocity was determined in the XYZ geocentric frame. The total in-flight velocity of the Cessna 172 aircraft was calculated as below [3]:

$$Vo = \sqrt{Vx^2 + Vy^2 + Vz^2}\ , \tag{3}$$

where Vx - velocity along to X axis; Vy - velocity along to Y axis; Vz - velocity along to Z axis; Vo - total velocity of aircraft.

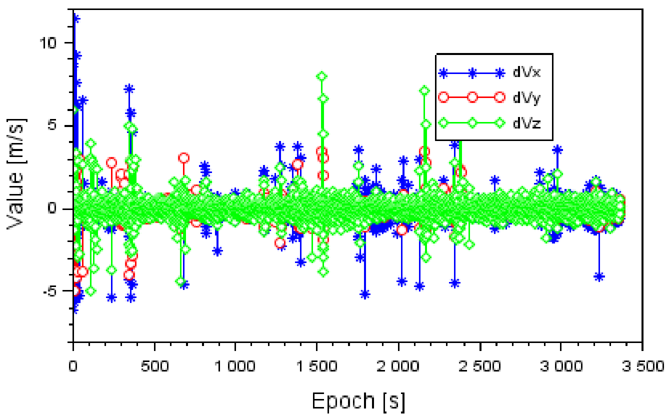
Fig. 3 presents the total velocity parameter values (Vx, Vy, Vz) of the Cessna 172 aircraft on the basis of the GLONASS solution. The Vo parameter takes the values from the numerical range +0.1 m/s to +74.5 m/s. Moreover, the mean value of the Vo parameter equals +39.2 m/s, with the median being +54.1 m/s. It should be added that more than 70% of the Vo parameter results is greater than 10m/s. Furthermore, more than 65% of the Vo parameter results is greater than 20m/s. On the other hand, less than 65% of the Vo parameter results is greater than 30m/s. Approximately 64% of the Vo parameter results is greater than 40 m/s whereas approximately 55% of the Vo parameter results is greater than 50 m/s. It should be noted that over 28% of the Vo parameter results is greater than 60 m/s whereas only 2% of the Vo parameter results exceeds the 70 m/s level. The highest values of the Vo total velocity parameter are noticeable in the middle flight phase whereas its lowest values are noticeable during the take-off and landing of the Cessna 172 aircraft at the military airport in Dęblin.



Source: Author's own work, developed on the basis of RTKLIB software package

Fig. 3 The total velocity of Cessna 172 aircraft

Fig. 4 presents the reliability of the Cessna 172 in-flight velocity determination for the GLONASS solution. Namely, the in-flight velocity values of the Cessna 172 aircraft obtained from the GLONASS solution were compared with the readings from the GPS sensor. The difference in velocity parameters (Vx, Vy, Vz) has been shown in Fig. 4.



Source: Author's own work, developed on the basis of RTKLIB software package

Fig. 4 The difference of velocity parameters of aircraft Cessna 172

The difference in the value of the Vx parameter (referred to in Fig. 4 as dVx) between the GLONASS and the GPS solution is from -6.1 m/s to +11.5 m/s. Moreover, the standard deviation for the dVx parameter value is 0.7 m/s. It should be added that approximately 96% of the dVx parameter results belongs to the -1m/s to +1 m/s range. The difference in the value of the Vy parameter (referred to in Fig. 4 as dVy) between the GLONASS and the GPS solution is from -5.0 m/s to +3.5 m/s. Moreover, the standard deviation for the dVy parameter value is 0.4 m/s. It should be added that approximately 98% of the dVy parameter results belongs to the -1 m/s to +1 m/s range. The difference in the value of the Vz parameter (referred to in Fig. 4 as dVz) between the GLONASS and the GPS solution is from -4.9 m/s to +8.1 m/s. Moreover, the standard deviation for the dVz parameter value is 0.6 m/s. It should be added that approximately 96% of the dVz parameter results belongs to the -1 m/s to +1 m/s range.

5. Conclusions

In the research work presented, the velocity of the Cessna 172 aircraft were verified on the basis of a GLONASS solution. The in-flight velocity of the Cessna 172 aircraft was determined in the XYZ geocentric frame on the basis of the kinematic motion of the aircraft. The in-flight velocity of the Cessna 172 aircraft was determined based on the basis of changes in the XYZ coordinates as a function of time. The coordinates of the Cessna 172 aircraft were determined using the SPP method on the basis of the GLONASS code observations. Satellite observation data were recorded by the Topcon HiperPro geodesic receiver placed in the cockpit of the Cessna 172. The test flight was performed in the vicinity of the military airport (EPDE) in Dęblin, Poland, and its duration was approximately 1 hour. Calculations concerning the Cessna 172 aircraft coordinates were performed in the RTKLIB (RTKPOST module) program package. Velocity parameters (Vx, Vy, Vz) were determined on the basis of the XYZ coordinates of the Cessna 172 aircraft. The Vx parameter values belong to the numerical range from -48.8 m/s to +58.1 m/s, whereas the respective values of the Vy parameter belong to the range of -61.6 m/s to +61.4 m/s, and those of the Vz from -49.1 m/s to +41.6 m/s. In the article, also total values of the Cessna 172 velocity were specified. The total velocity – Vo parameter – takes the values from the numerical range +0.1 m/s to +74.5 m/s. The work has also brought up the problem of reliability of determining the in-flight velocity of the Cessna 172 aircraft from the GLONASS solution against the background of the readings from the GPS sensor. It should be noted that over 96% of all the results of velocity parameter comparisons between the GPS and the GLONASS solution belong to the range of -1 m/s to +1 m/s.

Acknowledgements

The authors would like to thank T. Takasu for making the RTKLIB software package available at the website: ww.rtklib.com.

References

1. **Wierzbicki, D.; Krasuski, K.** 2015. Estimation of rotation angles based on GPS data from a UX5 Platform, Measurement Automation Monitoring 61(11): 516-520.
2. **Krasuski, K.** 2015. Application of Doppler effect for determination of aircraft position, Zeszyty Naukowe 2: 77-86. (in Polish)
3. **Ćwiklak, J.; Krasuski, K.; Jafernik, H.** 2017. Designation the velocity of Cessna 172 aircraft based on GPS data in flight test, 23rd International Conference Engineering Mechanics 2017, ISBN 978-80-214-5497-2, ISSN 1805-8248, pp. 262-265, Svratka, Czech Republic, 15 – 18 May 2017.
4. **He, K.** 2015. DGNSS Kinematic Position and Velocity Determination for Airborne Gravimetry, Scientific Technical Report 15/04, GFZ German Research Centre for Geosciences, doi: 10.2312/GFZ.b103-15044, pp.111-131.
5. **Grzegorzewski, M.** 2005. Navigating an aircraft by means of a position potential in three dimensional space, Annual of Navigation 9: 29-39.
6. **Ciećko, A.; Grunwald, G.; Kaźmierczak, R.; Dobek, M.; Gołąbek, P**. 2017. Examination of the Accuracy and Usefulness of Garmin and Suunto GNSS Devices during Navigation of the TS-11 "Iskra" Jet Aircraft, "Environmental Engineering" 10th International Conference, Vilnius Gediminas Technical University, Lithuania, 27–28 April 2017, pp. 1-8, DOI: https://doi.org/10.3846/enviro.2017.181.
7. **Salazar, D.** 2010. Precise GPS-based position, velocity and acceleration determination: Algorithms and tools, PhD thesis, Technical University of Catalonia, Spain, pp. 99-108.
8. **Wang, F.; Zhang, X.; Huang, J.** 2008. Error analysis and accuracy assessment of GPS absolute velocity determination without SA, Geo-spatial Information Science 11(2): 133-138, DOI: 10.1007/s11806-008-0038-3.
9. **van Graas, F.; Soloviev, A.** 2004. Precise Velocity Estimation Using a Stand-Alone GPS Receiver, NAVIGATION, Journal of The Institute of Navigation 51(4): 283-292, DOI: 10.1002/j.2161-4296.2004.tb00359.x.
10. **Qian, K.** 2017. Generic multisensor integration strategy and innovative terror analysis for integrated navigation, PhD thesis, York Univeristy, Toronto, Ontario, pp. 15-17.
11. **Krasuski, K.; Ćwiklak, J.** 2017. Application of the GLONASS code observations for the designation of coordinates of an aircraft in flight test mode: a case study, Scientific Journal of Silesian University of Technology. Series Transport 97: 69-80, DOI: 10.20858/sjsutst.2017.97.7.
12. **Ćwiklak, J.; Jafernik, H.** 2010. The monitoring system for aircraft and vehicles of public order services based on GNSS, Annual of Navigation 16: 15-24.
13. **Ochieng, W.Y.; Sauer, K.; Walsh, D.; Brodin, G.; Griffin, S.; Denney, M**. 2003. GPS Integrity and Potential Impact on Aviation Safety, The Journal of Navigation 56: 51-65, DOI: 10.1017/S0373463302002096.
14. **Takasu, T.** 2013. RTKLIB ver. 2.4.2 Manual, RTKLIB: An Open Source Program Package for GNSS Positioning, pp. 29-49. Paper available at website: http://www.rtklib.com/prog/manual_2.4.2.pdf, current on 2018.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Determination of the Geographical Location of a Central Facility

A. Seidlová[1], D. Šourek[2], M. Ledvinová[3]

[1]*University of Pardubice, Studentská 95, 53210, Pardubice, Czech Republic, E-mail: andrea.seidlova@upce.cz*
[2]*University of Pardubice, Studentská 95, 53210, Pardubice, Czech Republic, E-mail: david.sourek@upce.cz*
[3]*University of Pardubice, Studentská 95, 53210, Pardubice, Czech Republic, E-mail: michaela.ledvinova@upce.cz*

Abstract

Central facility location models are mostly used in logistics and transport networks to find the optimal position of a central warehouse, distribution centre or terminal. These models usually minimize the total transportation or distribution costs, which are based on the costs per unit, transport volumes and distances between existing customers and future center.
This paper analyses the different possibilities for determining the distances between customers and the central facility. The coordinates of existing facilities (customers) and a suitable coordinate system are the default inputs for solving. The distance can be expressed by different ways e.g. direct, corrected, rectangular or quadratic. This expression is usually sufficient for relative short distances (tens to hundreds km) in planar space. In the case of longer distances, the curvature of the earth´s surface should be considered. The paper deals with the possibility of using the geographical coordinates and orthodromic distance in location models. Authors focus on simple and practical solving with the use of commonly available software applications. The accuracy of the different distance calculations will be compared.
KEY WORDS: *facility location, geographical coordinates*

1. Introduction

Location models are used for location of various objects considering the interaction with other objects and/or service of defined area.

Covering problems lie in the location of service centers for a given set of objects with minimal costs, i.e. the number of service centers should be minimized. The maximum distance to service center is given for every served object. This problem can be applied to optimal location of central rescue, fire or police stations. The given maximal driving time to all served objects shall be respected [4, 5].

Center location problems lie in such service center location which minimizes the maximal (weighted) distance between every served object and the nearest service center. This problem can be applied to optimal location of central rescue, fire or police stations. The maximal driving time is not given but should be kept to a minimum.

Median location problems lie in such service center location which minimizes the sum of weighted distances between all served objects and the nearest service center. Served objects are rated at weights. Weight can represent the importance of the object or service requirements (e.g. required transport volumes). This problem can be applied to location of central warehouse, depot or logistic center based on minimization of total transportation costs. The problem is expressed by this function:

$$\min f(m) = \sum_v w(v) \cdot d(m,v), \tag{1}$$

where m - searched node in the graph $G=(V, H, c, w)$; $w(v)$ – weight of the node v; $d(m,v)$ - distance between m and v.

2. Definition of Location Area

The characteristics of location area are very important criteria for the definition of location problem. Problems can be divided into planar location problems, discrete location problems and network location problems.

Planar location is based on continuous location area. Service centers can be located anywhere in the defined geometric area. Fermat-Weber location problem which focuses on median location in Euclidean space is typical example of planar location. This problem is usually solved by Weiszfeld method [2, 4].

Each model of solving differs according to used metric. Taxicab geometry (manhattan distance, rectilinear distance) can be used to solve location problems in the city areas with rectangular street network or in industrial applications, e.g. for location of a machine in production hall. The distance d is:

$$d((x_1, y_1),(x_2, y_2)) = |x_1 - x_2| + |y_1 - y_2|, \tag{2}$$

where x_i, y_i – coordinates of the object i.

The direct distance in Euclidean metrics is:

$$d((x_1, y_1),(x_2, y_2)) = \sqrt{\left(x_1 - x_2\right)^2 + \left(y_1 - y_2\right)^2}\ , \tag{3}$$

where x_i,y_i – coordinates of the object i

In this case, the distance is displayed as a straight line. It can be used e.g. for location of a distribution center, logistic center or depot. In the case of longer distances (thousands of kilometers), the curvature of the earth´s surface should be considered. Distance can be then expressed by spherical trigonometry. [3]. The Earth´s surface is displayed as a reference sphere with radius R = 6378,*1 km* and the shortest distance d is displayed as an arc (orthodrome):

$$d((x_1, y_1),(x_2, y_2) = \arccos\left(\sin x_1 \sin x_2 + \cos x_1 \cos x_2 \cos\left(y_1 - y_2\right)\right) \cdot R \cdot \pi/180\ , \tag{4}$$

where x_1, x_2 – object latitude [°], y_1, y_2 - object longitude [°], R – radius of the Earth [km].

If we search for service centers location for customers in the whole world, the distance on the ellipsoid could be more accurate. [1].

The distance on sphere or ellipsoid can be used directly for air transport or partly for maritime transport. Road, rail and inland waterway transportation are actually realized in the transport network. The geometrical distances of each object in the space are only approximations of real distances in the transport network. The question is when could be used the transport network model (graph) and when would be the approximation more efficient. Many practical tasks really should be solved by the transport network model. But the construction of such model can be very difficult and time-consuming. The difficulty increases with the number of differently located customers. The customers in practice often demands the fast and simple way of solving.

3. Formulation of the Problem

Our objective is to find out how the different distance functions influence the location of central facility and how big is the difference between calculated distance and the driving distance in the real road network. We made the calculation for a set of fictive potential customers.

We solved the model example of one central facility location for the sample set of 39 randomly selected customers (cities) in Europe. We assumed their service by road transport. The distances between the customers varies from hundreds to thousands km. This model case is applicable to location of a logistic center, distribution center, terminal or one central warehouse for the customers with different transport volume requirements.

The main goal is to find the location with minimal total transportation costs. If we assume that the center facility can be located anywhere in the defined area, we can formulate the problem as median location in continuous space.

These inputs are required:

- location of each customer (geographical coordinates);
- requirements of each customer (e.g. transport volumes);
- transportation costs per unit and km.

4. Solution

We used Solver application in MS Excel. The constant weight of each customer (city) was determined according to the population. Starting center point was calculated using the Center of Gravity method.

The minimizing function in Euclidean metric (3) is:

$$\min f(x, y) = \sum_{i=1}^{m} w_i \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2}\ , \tag{5}$$

where x,y – coordinates of central facility, w_i – weight of customer i, x_i, y_i – coordinates of the customer i, m – the number of customers

Using the geographical coordinates in (5) will result the geographical coordinates of the central facility with minimal total transportation costs. The disadvantage lies in the impossibility of expressing distances between customers and central facility directly in km.

The minimizing function using spherical trigonometry (4) is:

$$\min f(x, y) = \sum_{i=1}^{m} w_i \cdot \arccos\left(\sin x \sin x_i + \cos x \cos x_i \cos\left(y - y_i\right)\right) \cdot R \cdot \pi/180\ , \tag{6}$$

where x – latitude of central facility [°]; y – longitude of central facility [°]; w_i – weight of customer i; x_i, y_i - coordinates of the customer I [°]; m – the number of customers; R – radius of the Earth [km].

We also have determined the real driving distances between customers and central facility (using map server mapy.cz) to compare the solution with.

The sample of the solving is shown in the Fig. 1.

1	City	Longitude	Latitude	w_i	d_2	d_{21}	d_{22}	N2	N3	d_{22}/d_2	d_{21}/d_2
2	Paris	2,35267550	48,8546710	21,38	733	890	822	15680,90	17574,36	1,1207	1,2135
3	Basel	7,60002047	47,5513984	1,68	352	464	402	591,04	675,36	1,1427	1,3189
4	Kopenhagen	12,58122057	55,6850819	5,03	844	1032	968	4245,13	4869,04	1,1470	1,2228
5	Lisboa	-9,14506674	38,7115362	5,17	2010	2501	2308	10394,23	11932,36	1,1480	1,2440
6	Bratislava	17,12956041	48,1529702	4,31	364	452	418	1567,25	1801,58	1,1495	1,2430
7	Wien	16,37150377	48,2079119	16,56	307	361	354	5089,51	5862,24	1,1518	1,1746
34	Praha	14,42692369	50,0868275	12,94	272	386	332	3522,50	4296,08	1,2196	1,4180
35	Ljubljana	14,50932115	46,0519651	2,78	286	360	355	796,16	986,90	1,2396	1,2570
36	Athens	23,74223170	37,9759042	30,58	1462	1988	1866	44720,27	57062,28	1,2760	1,3594
37	Roma	12,48783678	41,8999089	28,72	691	895	886	19851,40	25445,92	1,2818	1,2948
38	Zagreb	15,98698229	45,8074401	7,9	383	499	491	3025,86	3878,90	1,2819	1,3028
39	Marseilles	5,38407750	43,3084750	8,5	754	1035	968	6406,41	8228,00	1,2843	1,3732
40	Milano	9,18095201	45,4810126	13,24	374	539	482	4946,06	6381,68	1,2903	1,4428
41								**120836,7**	**148994,7**		
42	Center point	12,11758057	46,82026568								
43	Median (eucl.dist)	12,41676626	47,88663287								
44	Median (orthodrome)	12,23509829	48,10657963								
45	Median (cor. orthod.)	12,29208325	48,00172938								

Fig. 1 Solution of the central facility location in MS Excel

5. The Results of the Solution

The locations of the fictive customers are shown in the Fig. 2. The point 41 (Fig. 2) shows the starting center point calculated using the Center of Gravity method. The calculated location of the central facility using Euclidean metric and spherical trigonometry differs by about 30 km. The great circle distances (orthodrome) between central facility and customers vary from 49 to 2010 km (average 775 km). Only one customer (2,5%) is located within 100 km, 30% of customers is within 267-500 km, 38% of customers is within 500-1000 km and 23% is over 1000 km. From this point of view, the difference between the two used metrics is not very important.

Fig. 2 Set of customers with starting center

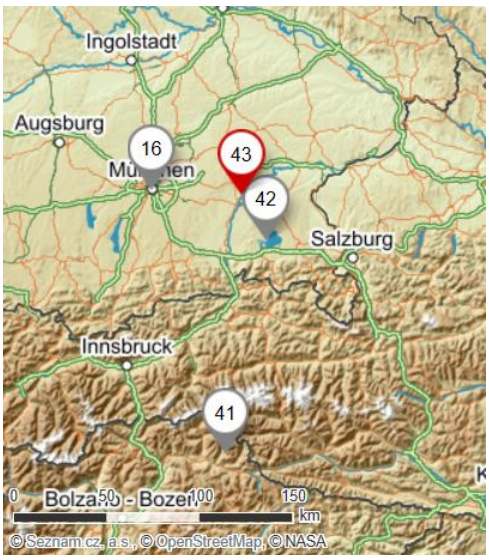


Fig. 3 Locations of central facility

The difference between calculated distances and the real driving distances on the road network will be more important for practice. We have determined the real distances for the shortest and the fastest route.

Differences between the shortest route and great circle distance vary between 12-28%. These differences point to significant importance of terrain on the route. All customers within interval of 20-28% are located beyond the Alps. The differences between the fastest route and great circle route are greater (17-44%). This is caused by choosing the routes outside the mountains and routes with higher driving speed. The real route chosen by carrier is very important. This decision-making process can be influenced by the established service model (time and distance criteria), character of the route (e.g. terrain) or by the costs (e.g. different fees, duty, taxes).

To refine the solution, we could use the corrected distance which considers the differences between theoretical solution and the usually used routes. We need to determine a suitable coefficient which can be based experimental on

the real distance of the selected set of customers (columns d_{22}/d_2 and d_{21}/d_2 in the Fig. 3). This coefficient can be used for customers in certain area with similar character.

6. Conclusions

The model example of central facility location in the area with diameter of about 2000 km shows that the differences between the solutions using different distance metrics are not very high. In our case, the corrected location of central facility is situated 18 km away from the calculated location (orthodrome). The difference is in the total transportation costs which can be the important economic indicator for the decision maker.

References

1. **Valencia, J.C.; Morales, J.O.C.; Flores, J.L.M.** 2016. Logistic model for the facility location problem on ellipsoids, International Journal of Engineering Business Management 8(49): 1-9.
2. **Chandrasekaran, R; Tamir. A.** 1990. Algebraic Optimization: The Fermat-Weber Location Problem, Mathematical Programming 46: 219-224.
3. **Katz, I.N. and Cooper, L.** 1980. Optimal Location on a Sphere. Computers & Mathematics with Applications 6: 175-196.
4. **Francis, R.; McGinnis, L.; White, J.** 1992. Facility Layout and Location: An Analytical Approach. New Jersey: Prentice-Hall, 444 p.
5. **Ledvinová, M.** 2013. Teorie dopravy. Pardubice: Univerzita Pardubice.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Analysis of Rejuvenation Process for Effective Hot-in-Place Recycling of Asphalt Pavement

R. Kleizienė[1], M. Paliukaitė[2], A. Vaitkus[3]

[1]*Road Research Institute of Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223, Vilnius, Lithuania, E-mail: rita.kleiziene@vgtu.lt*
[2] *Road Research Institute of Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223, Vilnius, Lithuania, E-mail: migle.paliukaite@vgtu.lt*
[3]*Road Research Institute of Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223, Vilnius, Lithuania, E-mail: audrius.vaitkus@vgtu.lt*

Abstract

The growing cargo transportation and mobility challenge increasing deterioration and repair demand of public roads infrastructure. Consequently, the road maintenance expenses remain an actual problem in state for which are constantly looking for advanced, efficient and durable pavement repair technologies. Most of the national rods of Lithuania is constructed flexible pavement structure with asphalt surface layers. One of the advantages of asphalt pavement is the quick and easy repair and the possibility recycle existing asphalt layers on the site by restoring the performance of the pavement and improving the ride quality. However, asphalt pavement mechanical properties changes with the time because of asphalt mixture ageing process. Bitumen rejuvenation process is a relevant topic related with reclaimed asphalt pavement (RAP) and hot-in place recycling (HIR) technologies, when aged bitumen properties can be restored to original condition. The main focus of this research is to analyze bitumen rejuvenation process and implementation for pavement repair, to review of bitumen aging phenomenon. This paper presents a comprehensive literature analysis and explicit design of experiment subjected to HIR technology improvement. This analysis allowed to determine the main criteria for bitumen rejuvenation process and to indicate the further experimental activities for development of the advanced HPR technology.
KEY WORDS: *hot-in-place recycling, asphalt repair, bitumen ageing, bitumen rejuvenation*

1. Introduction

According to the road maintenance and development program approved by the Lithuanian Road Administration under the Ministry of Transport and Communications the two thirds of national roads are constructed with asphalt pavement. Therefore, approximately 34% of the total yearly budget allocate to maintain, repair and reconstruct [1]. Highway agencies are looking for alternative technologies and mixture designs to more efficiently the modern, environmentally friendly, time and cost effective, durable solutions. The partial or full usage of recycle asphalt pavement (RAP) in new construction and rehabilitation projects became a regular practice in many countries [2-5]. Hot-in-place recycling (HIR) is an alternative technology that can promote the agencies preserve condition of pavement infrastructure with minimal resources of natural material and energy.

The HIR technology is a continuously processes of deteriorated asphalt pavement repair through the rehearing surface in situ, recycle and replace asphalt mixture in one operation cycle. HIR may also improve the properties of the upper or upper and lower layers of asphalt pavement by adding fresh materials such as bitumen, rejuvenator, aggregates or asphalt mix [6]. Although, HIR technology have evolve over the recent decades, the un controlled or incorrect application of technology may arise extensive thermal cracking, brittleness or bleeding of asphalt wearing layer [7]. The Multi-site recycling of asphalt pavement can be effective if the pavement condition and composition of asphalt mixture is assessed by the expert.

The objective of this scientific article is to analyze the principles of HIR technology, review of bitumen aging phenomenon, to present the design of experiment subjected to advanced asphalt recycling process and to highlight the recommendations for HIR improvement.

2. Analysis of Hot-in-Place Recycling Technology

The HIR technology was first adapted in 1930 in U.S., where distressed asphalt pavement where recycled in place without changing the compositions of asphalt mixture. This method hasn't changed essentially until the 1960s. In the 1960s, further development has transformed and HIR become more complex technology which consisted of several steps: heating the old wearing layer, milling the softened asphalt concrete, adding some fresh materials, mixing the regenerated mixture, laying and compacting the pavement. The recovery depth usually was about 20-25 mm, although in some cases the depth of 50 mm was also can be reached [8]. Once the HIR was introduced, it was difficult to reach the proper evenness level (roughness index) and constant thickness of asphalt pavement. Although the recent HIR

technology has been improved and provides the required roughness index, however there are still a number of restrictions on the application of this technology.

So, the outcome of HIR is a regenerated asphalt pavement with fresh aggregate interlock of 100% reclaimed asphalt pavement. Usually, the HIR is used when pavement distress emerges in the first 3-4 cm of the pavement with a minimal effect to pavement structural performance. The hot-in-pace recycling method according to maintenance stage and cause presented in Table 1.

According to literature review the effective implementation of HIR technology usually is assured by fulfilling the following stages:

1) expert assessment of the asphalt pavement (distress type and severity);
2) study of the asphalt pavement structural and drainage condition;
3) selection of the appropriate method for HIR (Table 1.);
4) design of regenerated asphalt mix in a laboratory;
5) qualitative implementation of HIR technology;
6) inspection and control of HIR technology.

However, the HIR is not recommended when there is a thin asphalt layer, structural rutting and fatigue cracking in the pavement, necessary drainage improvements, narrow roads, frequent pavement patching, numerous obstacles, and pavement surface is already several time treated. Also, HIR is not applicable to pavement where asphalt layers where reinforced with geosynthetics [12].

Table 1

The hot-in-pace recycling method according to maintenance stage and cause [11]

Maintenance stage	Maintenance cause	Hot-in-place recycling (+ eligible, - ineligible)		
		Reshape (method A)	Remix (method B)	Repave (method C)
		PCI (70:85)	PCI (60:75)	PCI (60:75)
		4 - 7 m	4 – 10 m	5 – 10 m
Regular	Rejuvenation of pavement aged by oxidation of asphalt	+	+	-
Periodical	Reduce surface cracking and defects	+	+	+
	Reduce wear rutting	+	+	+
	Improve texture and skid resistance	-	-	+
	Improve longitudinal and transverse profile	+	+	+

Notes: PCI – pavement performance index.
Reshape – HPR method with adding rejuvenator and without adding admixture, not changing the existing asphalt mixture composition.
Remix – HPR method with adding rejuvenators and admixture from aggregate or asphalt mixture, changing the existing asphalt mixture composition.
Repave – new asphalt wearing layer on the top of HPR treated (Repave or Remix) the existing asphalt pavement.

According to Asphalt Recycling and Reclaiming Association (ARRA) “Basic asphalt recycling manual” for efficacy of HIR pavement recycling the composition of reclaimed asphalt mixture have to be determined with experimental design focusing on the following characteristics: bitumen performance grade (PG), bitumen penetration/viscosity, mixture gradation, bitumen content, mixture air voids, mixture resistance to rutting, moisture damage and cracking.

So, before application of HIR, the reclaimed asphalt mixture composition has to be determined and its performance has to be evaluated with laboratory tests. The design of the recovered asphalt mix includes determination of the properties of the existing asphalt mixes as well as the amount and type of admixture and additives. The need for admixture, the additional aggregate or asphalt mixture, depends on pavement damage type and reclaimed asphalt mixture properties. Usually, if the amount of the admixture in the final reclaimed asphalt mix is more than 30%, then testing should be performed with three different content of the binder. Depending on the condition of the pavement and distress type the following admixtures are recommended to select:

- If rutting and/or shear deformations occur in the pavement, the aggregates mixture should be added to the RAP to reduce bitumen volume and increase the stability of the asphalt layer;
- If distress occurs due to the insufficient capacity of the pavement bearing capacity, the fresh asphalt mixture should be added and thicker pavement surface should be constructed;
- If distress occurs due to moisture, the slaked lime may be used;
- If distress occur due to aging (oxidation) of asphalt wearing layer, the rejuvenators should be added into bitumen to restore properties of bitumen [12].

During the design of reclaimed asphalt mixture composition, the existing asphalt pavement layers have to be tested in the depth at which it is a need to rehabilitate the pavement. According to LAKD (2010), the cores have to be drilled at least every 250 m. The number of drilled cores depends on the thickness of the asphalt layer and quantity need for mixture design tests. After reclaimed asphalt mixture composition design the protocol with detailed admixtures and

additives types and amounts have to deliver for further implementation of HIR to the investigated section of road pavement.

The HIR assembly depends on the manufacturer, but usually consists of primary heaters, milling, mixer truck, mixer, roller compactors. At the beginning of the HIR, heaters are used to remove moisture and warm up the asphalt pavement at temperature from 110°C to 160°C [9]. The heating temperature and time is regulated depending on rehabilitation depth and environmental conditions [10]. Then reheated asphalt pavement is milled at the project depth. According to FHWA (2013), it is necessary to visually check whether the milling teeth and the milling drum eliminates the surface of the asphalt layers at required depth, and observe whether the rough aggregate breaks. The break of asphalt concrete indicates insufficient heating of pavement surface and have to be avoided. The rejuvenator is dosed and spread under reheated and lose reclaimed asphalt mixture. If needed, the admixture is transferred to a double shaft mixer, where the fresh mixture of aggregates or asphalt is mixed with reheated lose asphalt layer mixture. The mixer is equipped with a series of devices for continuous mixing while keeping constant temperature with infrared heater. The fully mixed reclaimed asphalt mixture is transferred from the mixer to the bunker, and the pavement is applied to the paver. The asphalt concrete is paved verifying that the longitudinal joints are equally straight and cover at least 50 mm width from the previously shift. The pavement compaction is done at not less than 80°C temperature of asphalt layer with two rollers. The degree of asphalt layer compaction depends on mixture design project, however it is recommended to compact at least to 98.0%.

However, during HIR the effects of reheating temperature and mixing time has a crucial oxidation effect for already aged asphalt which without special additives results thermal cracking and raveling of asphalt pavement. The reheating temperature should be specified and controlled during entire HIR. Considering the asphalt (bitumen) ageing phenomenon the appropriate rejuvenator has to be selected and the necessary percentage (amount) has to be validated with laboratory tests. It is recommended to increase the percentage of rejuvenation for a longer mixing time and a rejuvenator with lower viscosity [13].

3. Bitumen Ageing and Rejuvenation

Bitumen aging is related to oxidation process which is one of the prevalent causes of the asphalt pavement susceptibility to fatigue and low temperature cracking. Nevertheless, bitumen aging can be slowed down or restored its initial properties by adding a special amount of rejuvenator. There are three methods of asphalt pavement rejuvenation [14]:

1. Mixing them with aged asphalt mixture at high temperature (140°C – 150°C) or spraying it onto the surface of asphalt pavement.
2. Rejuvenator Seal Materials (RSM), which is typically used after three to four years of pavement construction. (two parameters are important in the RSM procedure: effective penetration depth of rejuvenator and diffusion effect with asphalt binder).
3. Encapsulation process.

Rejuvenation process of bitumen is an essential topic related with reclaimed asphalt pavement (RAP) and hot-in place recycling (HIR) technologies, when aged bitumen properties can be improved or more or less restored by adding a special amount of rejuvenator and nanomaterial. Lots of studies have been done on rejuvenation methods such as mixing rejuvenating additives with aged asphalt at high temperature or spraying it into the surface of asphalt pavement, Rejuvenator Seal Materials (RMS), which is used after 3-4 years of pavement construction [15]. Another important aspect, modification of aged bitumen with aromatic oil, paraffinic oil, soft bitumen, and nano materials [16, 17]. During the rejuvenator process is very important to determine the appropriate content and type of rejuvenator so that the low temperature properties of the asphalt mixture can be improved [18]. Moghaddam and Baaj [14] analysed different types of rejuvenators in production of recycled hot mix asphalt. They claimed that good rejuvenators should properly react with aged binder and produce high quality recycled binder. However, over dosage of rejuvenator can cause other problems such as loss of adhesion and stripping of the asphalt film from aggregate. Simonen et al. (2013) explored bioflux solvent influence to bitumen aging, chemical and rheological characteristics. The amount of solvent depends on regenerated bitumen SARA (saturates, aromatics, resins and asphaltenes) fraction content [19]. Scientific interest has risen in exploring alternative binders and rejuvenators made from e.g. the recycled engine oil bottom (REOB), especially in Canada and North America. REOB contains chemical composition similar to conventional asphalt binders, however the composition is inconsistent [20]. The use of REOB for asphalt mixtures is controversial, uncertain, and may accelerate physical and chemical hardening, leaving the binder brittle enough to cause cracking in the asphalt pavement [21]. There are lots of other common alternative binders, such as bio-binder, palm oil, aromatic oil, and etc., which are being investigated and analysed by other scientists [22, 23]. Review of rejuvenators of asphalt pavement are given in Table 2.

The mechanical properties of aged bitumen can be regenerated using not only rejuvenators, but also nano materials such as nano-ZnO, nano-SiO2, or nano-TiO2. Using these type of additives, resistance to low-temperature cracking and permanent deformation can be improved. Blomberg et al. (2016) investigated stability of bitumen 160/220 modified with nano-clay (organically modified montmorillonite, C20A) and polymeric diphenylmethane diisocyanate (MID). Researchers investigated promising results adding 2% of MID and 10% C20A [24]. Modification of the neat binder with nano-SiO2 demonstrated significant improvements in physical and thermal properties with higher thermal stability and higher roughness. Selection of the optimum modifier content was based on Dynamic Shear Rheometer

(DSR), bitumen fatigue and rutting tests as well as work of adhesion analysis [25]. Using nano ZnO, the fatigue life of the asphalt mixtures increased significantly, the modified ACs had greater adhesion energy with aggregate and showed greater fatigue life [16]. Adding nano-clay in bitumen increased the viscosity of asphalt binders and improved the rutting and fatigue resistance of asphalt mixtures [24]. Addition of nano-silica into the control asphalt binder did not greatly affect the low-temperature properties of asphalt binders and mixtures [17]. In addition, a new approach for rejuvenation of aged bitumen was investigated using microcapsules (MicroWCOs) containing waste cooking oil. Waste cooking oil was easily penetrated into aged bitumen as a rejuvenator and recover its virgin properties, but was recognised uncertainly for long term performance [26].

Aged asphalt binder properties can be restored adding the rejuvenators and nano materials and prolonged the service-life of asphalt pavement. However, the detailed investigation should be done for determine the type and content of rejuvenators and nano materials and the impact for improving the aged bitumen physical and mechanical properties.

Table 2

Review of rejuvenators of asphalt pavement

Researcher	Rejuvenators	The amount of additives	Content of asphalt mixture
Romera et al. (2006)	CO[1)]	17%	83% RAP
	RO[2)]	20%	80% RAP
	150/200 bitumen	73%	17% RAP
Hicks (2002)	„Fog seal“[3)]	from 0,15 to 1,0 l/m^2	
Mallick RB et al. (2010)	„Reclamite“[4)]	0,9 % from mixture weight	100% RAP
Mallick et al. (2012)	„Renoil 1736“[5)]	1%	
Kandhal and Mallick (1997) „Tennessee DOT“ (1990)	AES-300PR (polimeras)[6)]	0,63 L/m^2 (0,13 gal/yd^2)	
Zaumanis et al. (2015)	Organic oil	12 % from amount of bitumen	100% RAP
	Distilled liquid rosin	12 % from amount of bitumen	100% RAP
	REOB	12 % from amount of bitumen	100% RAM
	Aromatic oil	12 % from amount of bitumen	100% RAM
Zaumanis et al. (2013)	„Nustar PG 64-22“	12 % from amount of bitumen	100% RAM
	Organic oil waste	12 % from amount of bitumen	100% RAM

Notes:
[1)] CO – an aliphatic-aromatic commercial oil
[2)] RO – an aliphatic-aromatic motor recycling oil
[3)] asphalt emulsion and water mixture with 1:1 ratio, the spreading amount relates to pavement surface condition
[4)] oil emulsion
[5)] 65,3 % alkyl aromatic oil and 27,7 % saturate oil
[6)] polymer modified, medium-strength anionic water-based asphalt emulsion

4. Experimental Methods for Advanced HPR Development

According to the literature analysis the method A of HIR applied to asphalt pavement sections with a pavement global pavement condition index (GPCI according to COST 354, 2008) of 2 to 3, the method B and C can be applied to pavement with GPCI from 3 up to 4 with the highest level of technology implementation. Flow chart for improved hot-in-place recycling mixture design is given in Fig. 4.

In order to improve the application of hot-in place recycling (HIR) technology in the regeneration of mixtures, bitumen aging processes and the effect on the performance of the asphalt wearing layer must be evaluated. Therefore, an extended experimental design plan has been developed. Due to complex research objective the experimental plan of bitumen binder regeneration and modification for long-life pavement project composed of three phases:

Phase I – determination of the innovative bitumen rejuvenation method (Fig. 1);

Phase II – implementation of the innovative method for recovered bitumen regeneration (Fig. 2);

Phase III – simulation of HIR technique in laboratory to evaluate bitumen rejuvenation influence to asphalt mixtures (Fig. 3).

The objective of phase I is to determine the effective rejuvenator and nano addictive and the optimal content to be used for bitumen chemical and rheological properties regeneration. Experimental plan for determination of innovative bitumen rejuvenation method is shown in Fig. 1. For this research phase, two asphalt binders were selected 70/100 and PMB 45/80-55 assuming that the majority of national and rural roads in Lithuania were paved with asphalt mixtures with these types of bitumen.

The objectives of phase II is to implement an innovative bitumen rejuvenation method for naturally aged and recovered bitumen regeneration. Experimental plan for implementation of innovative bitumen rejuvenation method is

shown in Fig. 2. Two bitumen recovered of reclaimed asphalt mixtures cored from distressed asphalt pavement sections in main road No.8 Panevėžys-Astrava-Sitkūnai and in Konstitucija av. of Vilnius city street.

The objective of phase III is to investigate the aged asphalt mixture from two distressed pavement sections, analyse mixture rejuvenation process under laboratory condition and to determine the optimal reclaimed asphalt mixtures blends and validate their mechanical properties and durability (Fig. 3).

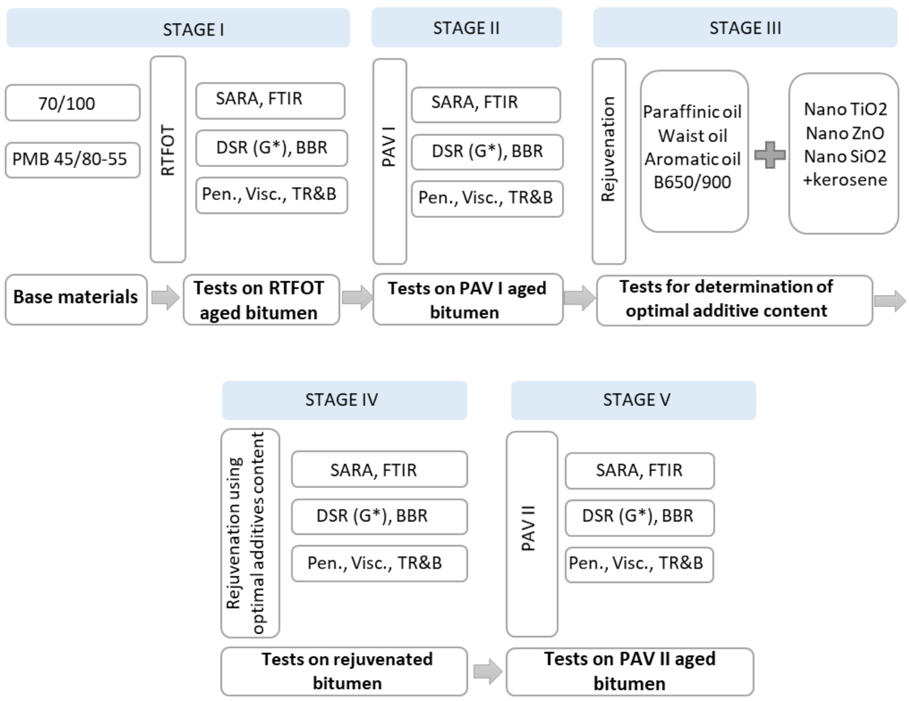


Fig. 1 Experimental plan for determination of innovative bitumen rejuvenation method (I phase)

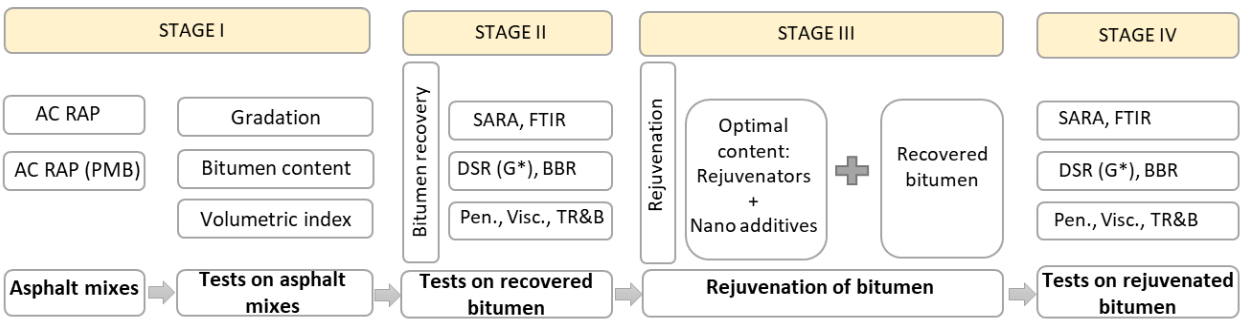


Fig. 2 Experimental plan for implementation of innovative bitumen rejuvenation method (II phase)

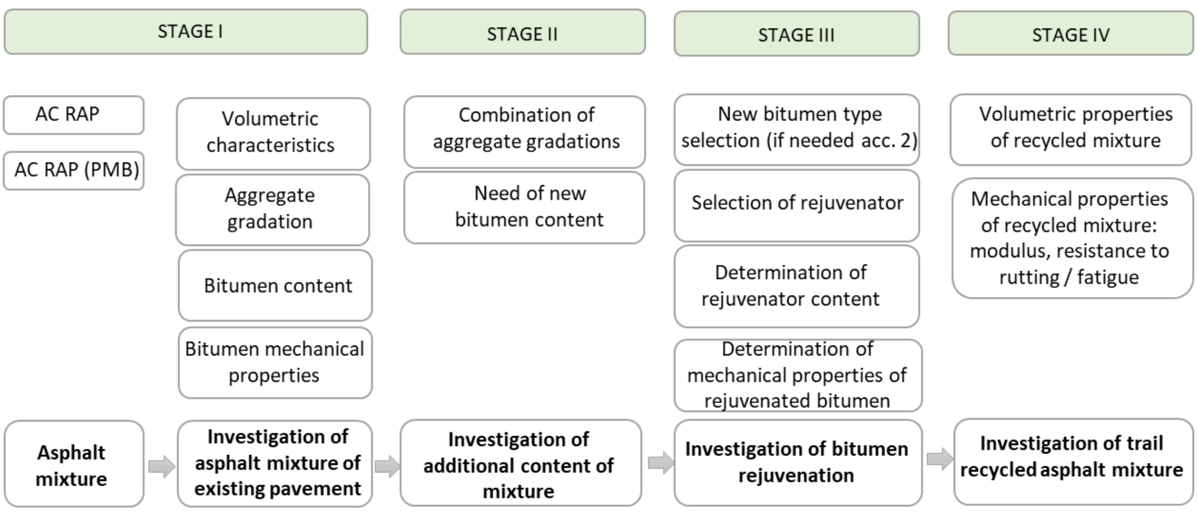


Fig. 3 Flow chart of improved hot-in-place recycling mixture design (III phase)

5. Conclusions

This paper analysed the Hot-In-place Recycling (HIR) technology, its application methods, bitumen ageing and rejuvenation process. From literature review the following observation can be made:

1. Qualified applied HIR technology is an efficient and effective repair (rehabilitation) method which restores the condition of distressed asphalt pavement surface in one operation.

2. The durability and performance of asphalt pavement repaired with HIR are related with reclaimed asphalt mixture design, which have to be done for each different asphalt pavement sections.

3. The heating effect and mixing time during HIR has a crucial oxidation effect for already aged asphalt, which without rejuvenators results thermal cracking and raveling of asphalt pavement. Considering the asphalt (bitumen) ageing phenomenon the appropriate rejuvenator has to be selected and the necessary percentage (amount) has to be validated with laboratory tests.

4. Aged asphalt binder properties can be restored and improve adding the rejuvenators and nano materials prolonging the service-life of asphalt pavement. However, the detailed investigation should be done for determine the type and content of rejuvenators and nano materials and the impact of modification to aged bitumen physical and mechanical properties.

5. It is recommended to revise the existing HIR regulations in Lithuania and to add the additional restriction for heating time and temperature, reclaimed asphalt mixture design, rejuvenator type and determination of optimal content as well as stringent control on site.

6. It is necessary to proceed and accomplished the proposed experimental plan which outcomes reveal the rejuvenation process of bitumen and asphalt mixture, determine the advanced reclaimed asphalt mixture design, and propose criteria for improvement of national regulations for HIR technology implementation.

Acknowledgments

This publication is a part of “Bitumen binder modification for long-life pavements” project which is funded by the European Social Funds under the No 09.3.3-LMT-K-712 “Development of Competences of Scientists, other Researchers and Students through Practical Research Activities” measure.

References

1. LAKD. 2017. Total funding of national state and local roads [online cit.: 2018-06-25]. Available from http//lakd.lrv.lt/uploads/lakd/documents/files/finansavimas/bendras2017.pdf
2. **Hafeez, I.; Ozer, H., Al-Qadi, IL.** 2014. Performance Characterization of Hot In-Place Recycled Asphalt Mixtures. J Transp Eng 140:4014029. Doi: 10.1061/(ASCE)TE.1943-5436.0000679.
3. **Yin, F.; Kaseer, F.; Arámbula-Mercado, E.; Epps Martin, A**. 2017. Characterising the long-term rejuvenating effectiveness of recycling agents on asphalt blends and mixtures with high RAP and RAS contents. Road Mater Pavement Des 18:273–292. Doi: 10.1080/14680629.2017.1389074.
4. **Bernier, A.; Zofka, A.; Yut, I.** 2012. Laboratory evaluation of rutting susceptibility of polymer-modified asphalt mixtures containing recycled pavements. Construction and Building Materials 31: 58–66. Doi: 10.1016/j.conbuildmat.2011.12.094.
5. **Vaitkus, A.; Čygas, D.; Kleizienė, R.** 2014. Research of Asphalt Pavement Rutting in Vilnius City Streets. Proceedings of the 9th International Conference “Environmental Engineering 2014”, 22-23 May, 2014, Vilnius, Lithuania. Vilnius Gediminas Technical University Press “Technika” 2014, Vilnius, Lithuania, pp 1–9.
6. **LAKD.** 2010. The rules for the use of materials and materials for the maintenance of road pavements and the layout of their layers (ĮT APM 10). Published in the website at www.valstybes-zinios.lt („Valstybės žinių“).
7. **Makowska, M.; Aromaa, K.; Pellinen, T.** 2017. The rheological transformation of bitumen during the recycling of repetitively aged asphalt pavement, Road Materials and Pavement Design 18: 50–65. Doi: 10.1080/14680629.2017.1304266.
8. **Terrel, RL.; Epps, J.A,; Sorenson, J.B.** 1997. New developments in hot in-place recycling of asphalt pavements. XIIIIth IRF World Meeting. Toronto, Ontairo Canada
9. **Russell, M.; Uhlmeyer, J.S.; DeVol, J.; Johnson, Ch.; Weston, J.** 2010. Evaluation of Hot In-Place Recycle. Post-Construction Report Experimental Feature 09-01.
10. FHWA. 2013. Construction Inspection Checklist #11 Hot In-Place Asphalt Recycling Application.
11. **Peshkin, D.; Smith, K.I.; Wolters, A.; Krstulovich, J.; Moulthrop, J.; Alvarado, C.** 2011. Preservation Approaches for High-Traffic-Volume Roadways. SHRP 2 REPORT S2-R26-RR-1. Washington D.C.
12. **Watson, D. 2011**. Hot In-Place Recycling Literature Review.
13. **Mallick, R.B.; Chen, B.L.; Daniel, J.S,; Kandhal, P.S.** 2012. Heating and its effect on hot in-place recycling of asphalt pavements with rejuvenator, International Journal of Pavement Research and Technology 5: 347–359
14. **Baghaee Moghaddam, T.; Baaj, H.** 2016. The use of rejuvenating agents in production of recycled hot mix asphalt: A systematic review, Construction and Building Materials 114: 805-816. Doi: 10.1016/j.conbuildmat. 2016.04.015
15. **Lin, J.; Hong, J.; Huang, C.; Liu, J.; Wu, Sh.** 2014. Effectiveness of rejuvenator seal materials on performance of

asphalt pavement, Construction and Building Materials 55: 63-68. Doi: 10.1016/j.conbuildmat.2014.01.018.
16. **Azarhoosh, A.R.; Nejad, F.M.; Khodaii, A**. 2016. Nanomaterial and fatigue cracking of hot mix asphalt, Road Materials and Pavement Design 629: 1-14. Doi: 10.1080/14680629.2016.1261724
17. **Yang, J.; Tighe, S.** 2013. A Review of Advances of Nanotechnology in Asphalt Mixtures, Procedia - Socials Behavioral Science 96: 1269-1276. Doi: 10.1016/j.sbspro.2013.08.144.
18. **Reyes-Ortiz, O.; Berardinelli, E.; Alvarez, A.E.; Carvajal-Muñoz, J.S.; Fuentes, L.G.** 2012. Evaluation of Hot Mix Asphalt Mixtures with Replacement of Aggregates by Reclaimed Asphalt Pavement (RAP) Material, Procedia – Socials Behavioral Science 53: 379-388 . doi: 10.1016/j.sbspro.2012.09.889.
19. **Simonen, M.; Blomberg, T.; Pellinen, T.; Makowska, M.; Valtonen, J.** 2013. Curing and ageing of biofluxed bitumen: a physicochemical approach, Road Materials Pavement Design 14:159-177. doi: 10.1080/14680629. 2012.755933.
20. **Kaskow, J.; van Poppelen, S.; Hesp.** 2018. Methods for the Quantification of Recycled Engine Oil Bottoms in Performance-Graded Asphalt Cement, Journal of Materials in Civil Engineering 30(2). Doi: 10.1061/(ASCE)MT. 1943-5533.0002137.
21. **Johnson, K.A.; Hesp, S.** 2014. Effect of Waste Engine Oil Residue on Quality and Durability of SHRP Materials Reference Library Binders. Transportation Research Record: Journal of the Transportation Research Board 2. 444: 102-109 . doi: 10.3141/2444-12.
22. **Peralta, J.; Williams, C.R.; Marjorie Rover; Hugo M.R.D. Silva.** 2012. Alternative Binders for Sustainable Asphalt Pavements. Dev rubber-modified fractionated bio-oil use as noncrude Pet Bind Flex pavements 23–36.
23. **Li, Y.; Moraes, R.; Lyngdal, E.; Bahia, H.** 2016. Effect of Polymer and Oil Modification on the Aging Susceptibility of Asphalt Binders, Transportation Research Record: Journal of the Transportation Research Board 2574: 28-37. Doi: 10.3141/2574-03.
24. **Ortega, F.J.; Navarro, F.J.; García-Morales, M.; McNally, T.** 2015. Thermo-mechanical behaviour and structure of novel bitumen/nanoclay/MDI composites, Compos Part B Eng 76: 192-200. Doi: 10.1016/j.compositesb. 2015.02.030.
25. **Leiva-Villacorta, F.; Vargas-Nordcbeck, A.** 2017. Optimum content of nano-silica to ensure proper performance of an asphalt binder, Road Materials and Pavement Design 629: 1-12. Doi: 10.1080/14680629.2017.1385510.
26. **Su, J.F.; Qiu, J.; Schlangen, E.; Wang, Y.Y.** 2015. Investigation the possibility of a new approach of using microcapsules containing waste cooking oil: In situ rejuvenation for aged bitumen, Construction and Building Materials 74: 83-92. Doi: 10.1016/j.conbuildmat.2014.10.018.
27. **Romera, R.; Santamaría, A.; Peña, J.J.; Muñoz, M.E.; Barral, M.; García, E.** 2006. Rheological aspects of the rejuvenation of aged bitumen, Rheol Acta 45: 474-478. Doi: 10.1007/s00397-005-0078-7.
28. **Hicks, R.G.** 2002. Purpose and Use of Fog Seals and Rejuvenators. Sealer Binder Workshop, Foundation for Pavement Preservation, Federal Highway Administration.
29. **Mallick, R.B.; Tao, M.; O'Sullivan, K.** 2010. Why not use rejuvenator for 100% RAP recycling? Transportation Research Board annual meeting.
30. **Kandhal, P.S.; Mallick, R.B.** 1997. Pavement Recycling Guidelines for State and Local Governments: Participant's Reference Book. Fhwa-Sa-98-042 301.
31. **Zaumanis, M.; Mallick, R.B.; Frank, R.** 2015. Evaluation of different recycling agents for restoring aged asphalt binder and performance of 100% recycled asphalt, Materials and Structures Volume 48: 2475-2488. Doi: 10.1617/s11527-014-0332-5.
32. **Zaumanis, M.; Mallick, R.B.; Frank, R.** 2013. Use of Rejuvenators for Production of Sustainable High Content Rap Hot Mix Asphalt. XXVIII International Baltic Road Conference. 1–10

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Neural Algorithm of Driver Selection for Transport Tasks

M. Kijek[1], M. Brzeziński[1], J. Zelkowski[1], Ł. Rykała[2]

[1]*Military University of Technology, Faculty of Logistics, Institute of Logistics, gen. Witolda Urbanowicza 2, 00-908, Warsaw, Poland, E-mail: magdalena.kijek@wat.edu.pl, marian.brzezinski@wat.edu.pl, jaroslaw.zelkowski@wat.edu.pl*
[2]*Military University of Technology, Faculty of Mechanical Engineering, Institute of Machine Buildings, gen. Witolda Urbanowicza 2, 00-908, Warsaw, Poland, E-mail: lukasz.rykala@wat.edu.pl*

Abstract

The transport services market and competition are growing, but also the demand for transported cargo is increasing. The growing requirements of the modern market mean that enterprises have to maximally optimize the transport process of each entity participating in this process. The article will specify and characterize an original driver selection algorithm for carrying out transport tasks. Discussed algorithm for solving mentioned problem using artificial neural networks will be presented based on actual data on the use of vehicles of the transport company.
KEY WORDS: *artificial intelligence, neural network, optimization, transport*

1. Introduction

The demand for transport services is growing, and the most commonly used means of transport, due to the availability of cargo delivery, are motor vehicles. Effective fleet management enables enterprises to reduce costs. Enterprises are increasingly looking for modern solutions that allow them to control the work of their drivers (i.e. fuel consumption, times of engine overload, exceeding the permitted speeds limits or working time) and allow them to constantly monitor where they are exactly. Analysis of database allows to improve the safety, quality and cost-effectiveness of transport services. The article presents statistical data of a transport company that offers transport services for bulk materials. The obtained data made it possible to develop the author's own assessment and selection algorithm to perform transport tasks.

2. Characteristics of the Research Problem

The realization of the driver's job doesn't end only with delivering the cargo to the customer. The transport is carried out and analyzed under a multi-aspect angle (Fig. 1). Driver's car fuel usage is a very important factor as other aspects that relate to the ride itself:

- Rule-based driving method, that is compliance with standards, limits and all regulations in road traffic. Thus, the measure of this way of driving may be the low number of fines (or their absence) or the percentage of speeding of vehicles on the route.
- An accident rate is related to the driving style, how often a given vehicle is damaged while performing transport tasks.
- The way the vehicle is used is an expensive part of every fleet. It is clearly associated with vehicle failures. The operation of the vehicle depends on the driving technique (i.e. the average number of brakes or stops, the time of inertial motion, or excessive speed of the driver).
- Fuel consumption, by analyzing the amount of consumed fuel, it can be determined whether a given driver was driving economically. Driving technique can be established, i.e. whether he used eco-driving principles (moderate acceleration, driving whenever possible in the highest gear, engine braking).
- Normal driving - slow acceleration, engine braking, driving on the highest gear.
- Aggressive driving - dynamic acceleration, impulsive braking, dynamic changes of gears.
- Safety of the transported cargo - this parameter is directly related to the others, because it depends whether the transported cargo will be delivered in the appropriate quality.
- Communicability and customer relations, because the driver is the company's showcase. He's the direct contractor of transport tasks.

The subject of research is a transport company whose business is based on the transport of bulk materials, including cereals, animal feeds, loose vegetables, loose food products (flour, milk powder etc.). The company employs 14 drivers and 3 people involved in the organization of transport processes. The car fleet are Volvo 4x2 tractor units. On the other hand, the subject of research is statistical data on the operation of vehicles for a period of 3 years for 14 drivers.

Fig. 2 presents statistical data of 3 selected drivers in particular months of one selected year. One can observe a large variation in the covered distance in the range of about 7 thousand up to 15 thousand km. Different values of the average fuel usage parameter are related to this (Fig. 3). In turn, drivers drove most of the route with a full load (the average percentage of the vehicle load was classified at 82%) (Fig. 4).

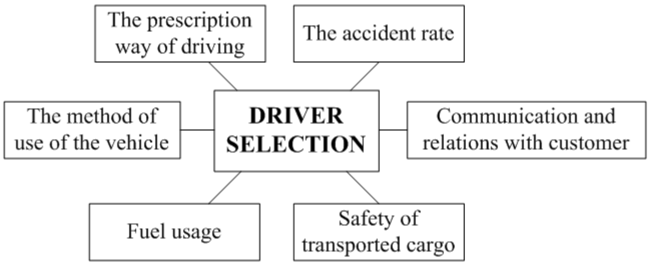


Fig. 1 Selected aspects of driver selection for transport tasks

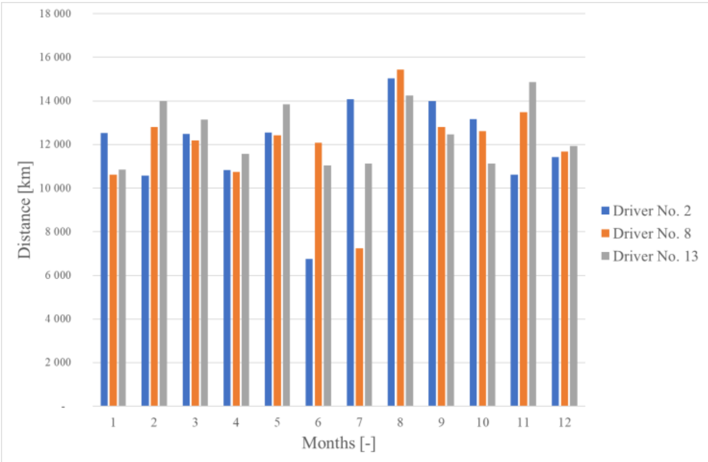


Fig. 2 Chart of traveled distance in following months for selected drivers No. 2, 8 and 13

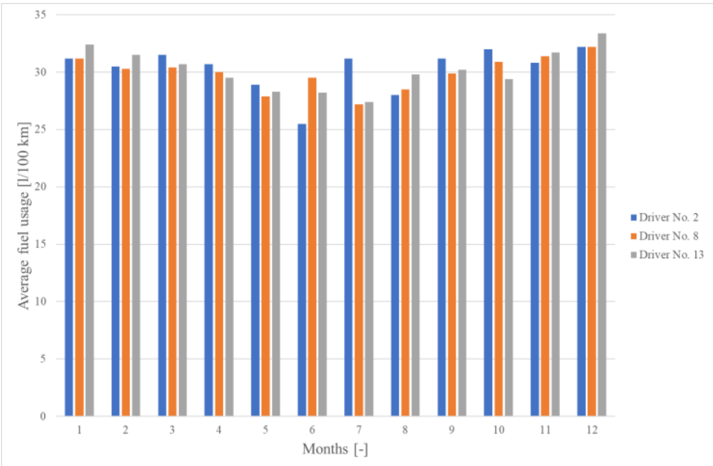


Fig. 3 Chart of average fuel usage in following months for selected drivers No. 2, 8 and 13

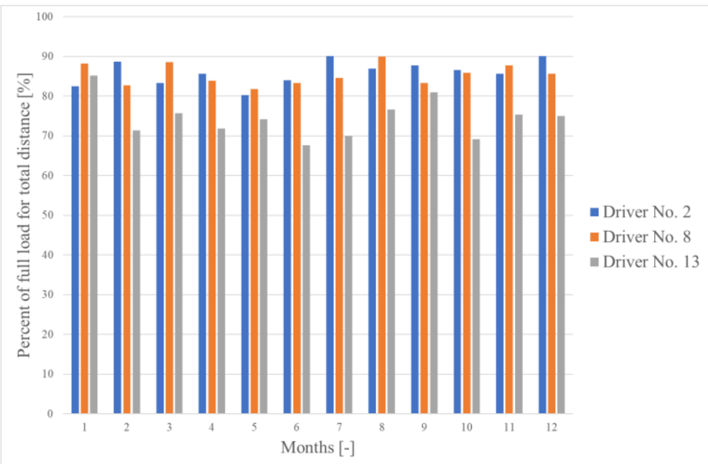


Fig. 4 Chart of percentage of traveled distance with full load in following months for selected drivers No. 2, 8 and 13

Fig. 5 characterizes the driving style of selected drivers. Based on the presented data, we can conclude that driver No. 2 was more heavily loading the engine compared to the other two. However, the impact on the analyzed results may also have a diversity of covered routes and atmospheric conditions.

Fig. 6 shows the average values of fuel usage and distance traveled by all drivers in individual months. The highest average fuel usage occurs in the winter months, i.e. December, January (about 32 [l/100 km]), while the lowest occurs in the summer months, i.e. June and August (about 29 [l/100 km]). In turn, the traveled distance is in the range from about 28 thousand to about 32 thousand km.

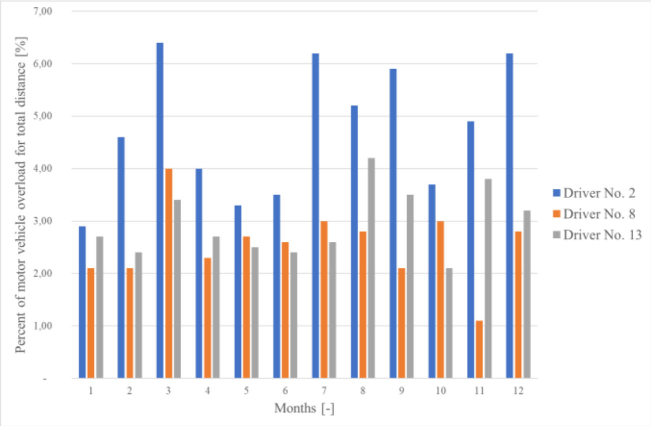


Fig. 5 Chart of percentage of traveled distance with vehicle's motor overload in following months for selected drivers No. 2, 8 and 13

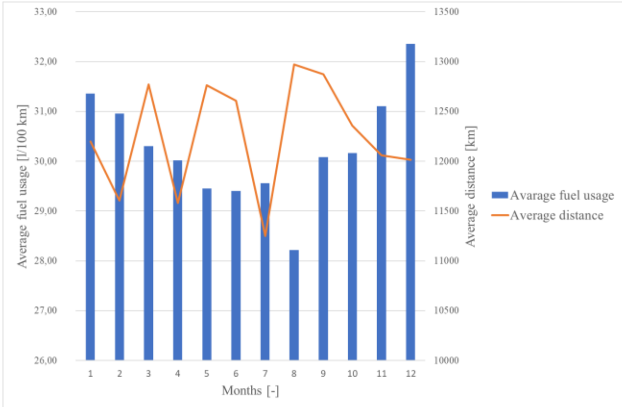


Fig. 6 Charts of average fuel usage and average travelled distance in following months for all drivers

Comparing the above results with the results of the average fuel usage (Fig. 3) and average traveled distance (Fig. 2) for selected drivers, it can be assumed, due to diversity of data, that there is a possibility of reducing costs by appropriate selection of drivers for a specific task.

3. Neural Algorithm of Driver Selection for Transport Tasks

One of the most important factors affecting transport costs is fuel consumption. The use of an appropriate driving technique (optimum load distribution, avoiding unnecessary braking, etc.) allows reducing it. Additional factors affecting fuel consumption are the condition and density of the road networks. An extensive road network connection allows selecting rational route, while good road surface condition reduces rolling resistance and general energy loss for vehicle [4, 7].

Each driver has his own driving style. Usually, these people have extensive experience in this type of work and they can adapt to the constantly changing conditions on the road. The paper tends to create a "driver profile" based on the presented statistical data from a transport company using artificial neural networks. The proposed approach is based on a mentioned neural network, which together with the developed algorithm makes it possible to select the right driver for the designated transport task. In turn, modeling based on methods of artificial intelligence, i.e. artificial neural networks or fuzzy logic, is the subject of various scientific articles [2, 3, 5].

The created neural network was developed using the Neural Networks toolbox included in the Matlab/Simulink software. It's a feedforward two-layer neural network consisting of 50 neurons in the first layer (hidden layer) and 3 neurons in the output layer (Fig. 7) [6].

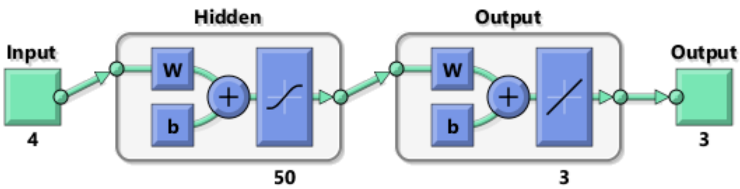


Fig. 7 Structure of proposed neural network

Mentioned structure has the following input signals:

- Traveled distance [km];
- Percentage of traveled distance with full load [%];
- Month No. [-];
- Driver No. [-].

In turn, the output signals to the network are:

- Average fuel usage [l/100km];
- Percentage of traveled distance with neutral gear [%];
- Percentage of traveled distance with vehicle's motor overload [%].

Bayesian regularization backpropagation method was used for process of learning neural network. It's a training technique that updates the weight and bias values according to Levenberg-Marquardt algorithm [1].

The process of learning neural network consisted of 631 epochs and lasted 23 seconds. Additionally, the learning process was interrupted due to the too high value of the Marquardt adjustment parameter (Mu) of the order of magnitude 10^{50} (Fig. 8) [1].

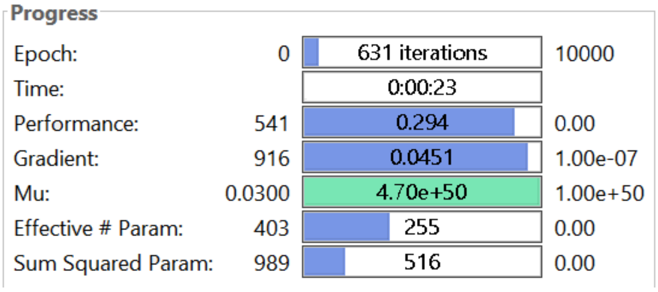


Fig. 8 Summary of neural network learning process

The course of the value of the objective function (mse – mean squared error) reached the minimum in the 379-th epoch (Fig. 9). The histogram of the learning process errors for the training and testing sets of the neural network is shown in Fig. 10. In turn, the course of the gradient function is characterized by its variable nature of the function, which minimizes the objective function, while from around 380-th epoch the course of the function is constant (Fig. 11).

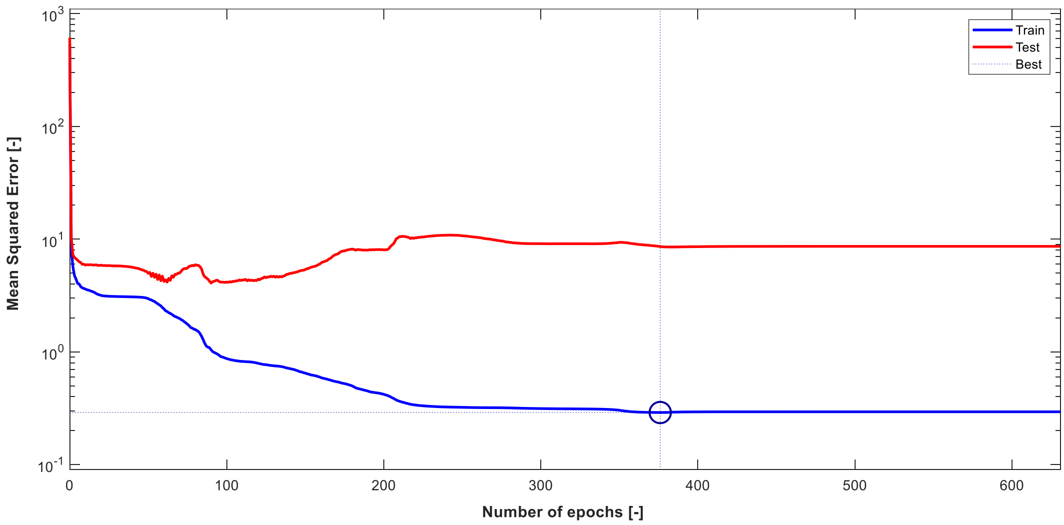


Fig. 9 Graph of the performance of the neural network learning process

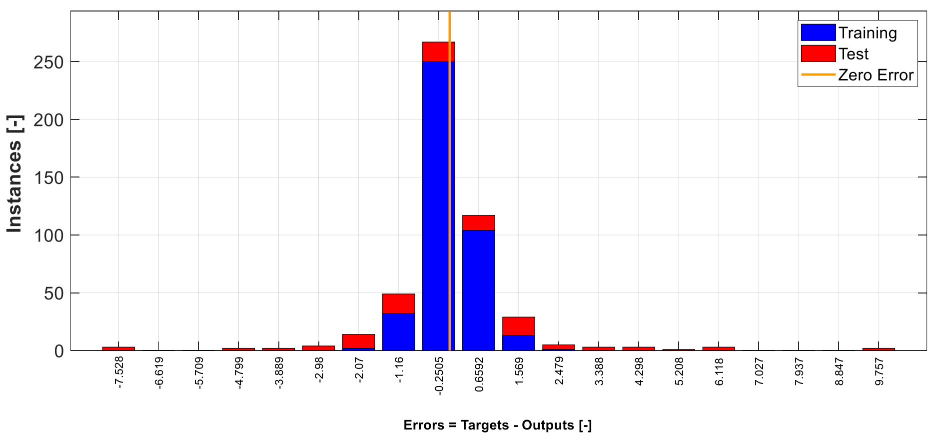


Fig. 10 Histogram of errors of the neural network learning process

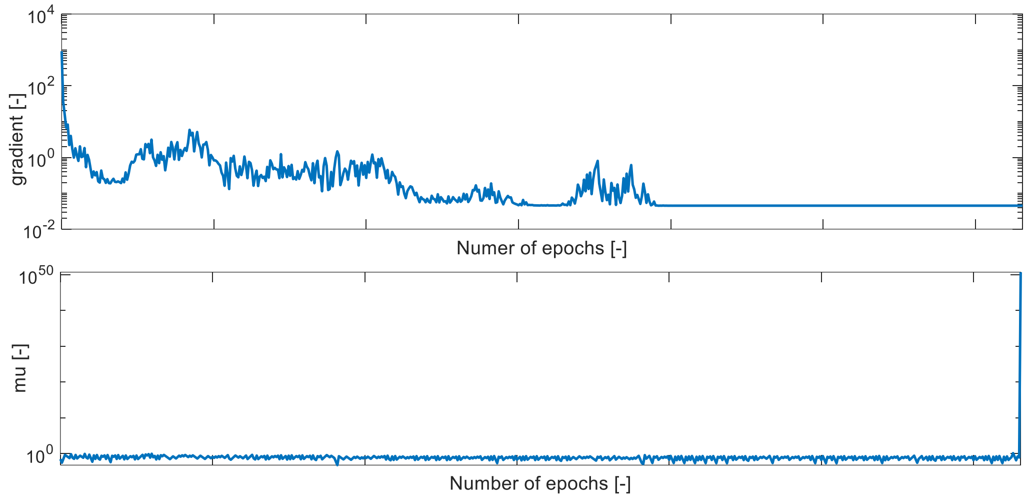


Fig. 11 Graph of the selected parameters of the neural network learning process

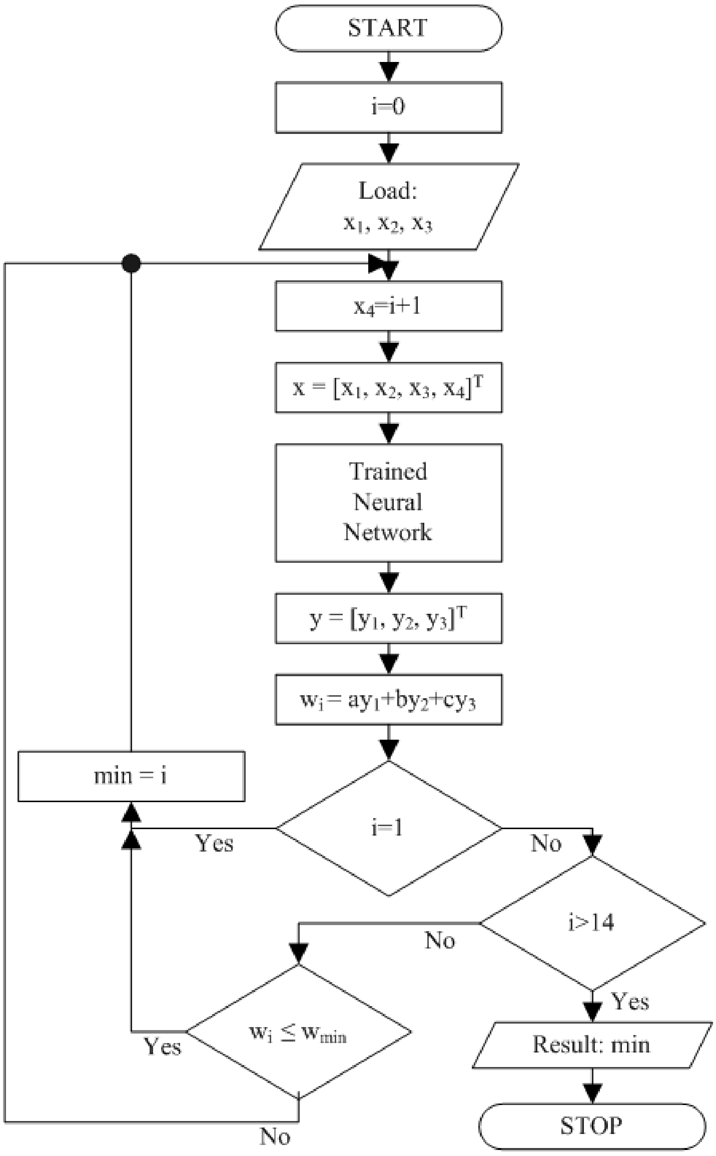


Fig. 12 Diagram block of the algorithm of driver selection

The following variables were adopted in the schematic of the proposed algorithm (Fig. 12): x_1 - traveled distance [km], x_2 - percentage of traveled distance with full load [%], x_3 - month No. [-], x_4 - driver No. (1, 2, …, 14) [-] , y_1 - average fuel usage [l/100km], y_2 - percentage of traveled distance with neutral gear [%], y_3 - percentage of traveled distance with vehicle's motor overload [%]. The variable w is the objective function which parameters: a, b, c depend

on the preferences of the person managing the transport in the company. The result of the algorithm is the number of the optimal driver (minimizing the mentioned objective function *w*) to perform the designated transport task.

The values of the objective function *w* can also be determined based on the fuzzy model, e.g. Mamdami or Takagi-Sugeno.

4. Conclusions

In order to select the optimal driver to perform transport tasks, neural networks were used, which are commonly used to optimize processes from the various areas of technical sciences. The proposed algorithm and results of the transport company allow to determine the predicted operating parameters of each driver. Due to the small data set (period of 3 years), it is planned to extend the research in this area in the future.

References

1. **Demuth, H.; Beale, M.; Hagan, M.** 2018. Neural network toolbox™, Reference. pp. 493-496.
2. **Brzeziński, M.; Kijek, M.; Gontarczyk, M.; Rykała, Ł.** 2017. Zelkowski J. Fuzzy modeling of evaluation logistic systems, Transport Means 2017. Kaunas: Proceedings of the 21th International Conference. p. 377-382.
3. **Rykała, Ł**. 2018. Modelowanie ruchu niejednorodnych brył z wykorzystaniem metod sztucznej inteligencji, Przegląd Mechaniczny 5: 21-26.
4. **Świder, P.** 2012. Teoria ruchu samochodów cz. 1, Kraków: Wydawnictwo Politechniki Krakowskiej. pp. 17-49.
5. **Świderski, A.; Józwiak, A.; Jachimowski, R.** 2018. Operational quality measures of vehicles applied for the transport services evaluation using artificial neural networks, Maintenance and Reliability 20(2): 292-299.
6. **Tadeusiewicz R.** 1993. Sieci neuronowe (Vol. 180). Warsaw: Akademicka Oficyna Wydawnicza. pp. 27-47.
7. **Żak, J.** 2005. Wielokryterialne wspomaganie decyzji w transporcie drogowym. Poznań: Wydawnictwo Politechniki Poznańskiej. pp. 39-40.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

Mathematical Model of the off-Road Vehicle Suspension

M. Maloch[1], S. Cornak[2]

[1]*University of Defence in Brno, Kounicova 65, 612 00 Brno, Czech Republic, E-mail: martin.maloch@unob.cz*
[2]*University of Defence in Brno, Kounicova 65, 612 00 Brno, Czech Republic, E-mail: stefan.cornak@unob.cz*

Abstract

Quarter car model is often used in many publications as a primal model because solving possible errors is easier due to lower degrees of freedom. In case of the presented paper, the quarter car model is used too, but of the vehicle with four axles, so the minimal number of degrees of freedom is four. Thus, a pitch oriented model of a “bicycle” type has been suggested. Simulation in Multi Body System from MSC Software, Adams, was implemented. The last part of the paper consists of a comparison of double wishbone suspension, ordinary and modified layout. The evaluations were carried out with regard to the passengers’ comfort and road stability.
KEY WORDS: *double wishbone suspension, quarter car model, mathematical model, off-road vehicle*

1. Introduction

Utilization of mathematical models and Multi Body Systems (MBS) can lead to great economical savings, in case of testing the vehicle´s ability to overcome various obstacles. Primal tests and troubleshootings can be performed on models, instead of real vehicle with running costs and possibility of unwanted damage. Last part should be the real test which is supposed to validate the model. However, creating a model is very complex job, so as is the ability of understanding all processes which are happening in the model. That is the main reason why is it necessary of start with simpler models- less degrees of freedom (DOF), simple obstacles, low traveling speeds. With wheeled vehicles it is necessary to fully understand tire models, properties of bushings. Last but not least, it is crucial to know right input parameters. First models should be created with linear parameters, damping characteristics, stiffness characteristics, due to simplicity. The best option is to have a mathematical model, supported by MBS or vice versa. With comparison of these models, more insight into the topic is provided.

Since most of the publications [3], [4] utilize only one kind of model, the decision has been made, to gradually build up bigger models with more DOFs and complicated parameters, with a possibility of verification by both models- mathematical and MBS.

2. Quarter Car of 8x8 Vehicle Passive Suspension System

Presented in Fig. 1 is the arrangement of the linear suspension system. It consists of sprung mass m_S , pitch axis moment of inertia J ,unsprung mass of the front wheel and links m_{WhF}, unsprung mass of the rear wheel and links m_{WhR}. Characteristics of the modified double wishbone suspension are: k_{SusF} and k_{SusR} as the spring stiffness for the front and rear coil spring, c_{SusF} and c_{SusR} for the damping coefficient for the front and rear hydraulic shock absorber. Vertical stiffness and vertical damping of the tires are k_{WhF} and c_{WhF} for the front tire, k_{WhR} and c_{WhR} for the rear one. 4 DOF consists of vertical movement of each of the unsprung masses- z_{WhF} and z_{WhR} for the front and rear, vertical motion of centre of gravity for the sprung mass- z_{cg} and a pitch of the sprung mass φ. The movement is created by the input displacement to the wheels- z_{gF} and z_{gR} for the front and rear wheel. Distances between the centre of wheels and centre of gravity are a and b for the front wheel and rear wheel respectively.

3. Mathematical Modeling

Using the Newton´s second law of the motion on the system in Fig. 1, four equations of motion are obtained.

$$m_s \cdot \ddot{z}_{cg} = -k_{SusF} \cdot \left(z_{cg} - a \cdot \varphi\right) - c_{SusF} \cdot \left(\dot{z}_{cg} - a \cdot \dot{\varphi}\right) + k_{SusF} \cdot z_{WhF} + c_{SusF} \cdot \dot{z}_{WhF} - k_{SusR} \cdot \left(z_{cg} + b \cdot \varphi\right) - \\ - c_{SusR} \cdot \left(\dot{z}_{cg} + b \cdot \dot{\varphi}\right) + k_{SusR} \cdot z_{WhR} + c_{SusR} \cdot \dot{z}_{WhR}; \tag{1}$$

$$J \cdot \ddot{\varphi} = \left(-k_{SusF} \cdot a\right) \cdot \left(z_{cg} + \varphi \cdot (-a)\right) + c_{SusF} \cdot a \cdot \left(\dot{z}_{cg} - a \cdot \dot{\varphi}\right) + \left(-k_{SusF} \cdot a \cdot z_{WhF}\right) + \left(-c_{SusF} \cdot a \cdot \dot{z}_{WhF}\right) + \\ + \left(-k_{SusR} \cdot b\right) \cdot \left(z_{cg} + b \cdot \varphi\right) - c_{SusR} \cdot b \cdot \left(\dot{z}_{cg} + b \cdot \dot{\varphi}\right) + k_{SusR} \cdot b \cdot z_{WhR} + c_{SusR} \cdot b \cdot \dot{z}_{WhR}; \tag{2}$$

$$m_{WhF} \cdot \ddot{z}_{WhF} = k_{SusF} \cdot \left(z_{cg} + \varphi \cdot (-a)\right) + c_{SusF} \cdot \left(\dot{z}_{cg} - a \cdot \dot{\varphi}\right) + \left(-k_{WhF} \cdot z_{WhF}\right) - k_{SusF} \cdot z_{WhF} - \\ - c_{WhF} \cdot \dot{z}_{WhF} - c_{SusF} \cdot \dot{z}_{WhF} + k_{WhF} \cdot z_{gF}; \tag{3}$$

$$m_{WhR}\cdot\ddot{z}_{WhR}=k_{SusR}\cdot\left(z_{cg}+\varphi\cdot b\right)+c_{SusR}\cdot\left(\dot{z}_{cg}+b\cdot\dot{\varphi}\right)+\left(-k_{WhR}\cdot z_{WhR}\right)-k_{SusR}\cdot z_{WhR}-c_{WhR}\cdot\dot{z}_{WhR}-$$
$$-c_{SusR}\cdot\dot{z}_{WhR}+k_{WhR}\cdot z_{gR},\tag{4}$$

where $\ddot{z}_{WhR}, \dot{z}_{WhR}, \ddot{z}_{WhF}, \dot{z}_{WhF}, \ddot{z}_{cg}, \dot{z}_{cg}, \ddot{\varphi}, \dot{\varphi}$ are the acceleration and velocity of the rear wheel, front wheel, sprung mass and a pitch of the sprung mass.

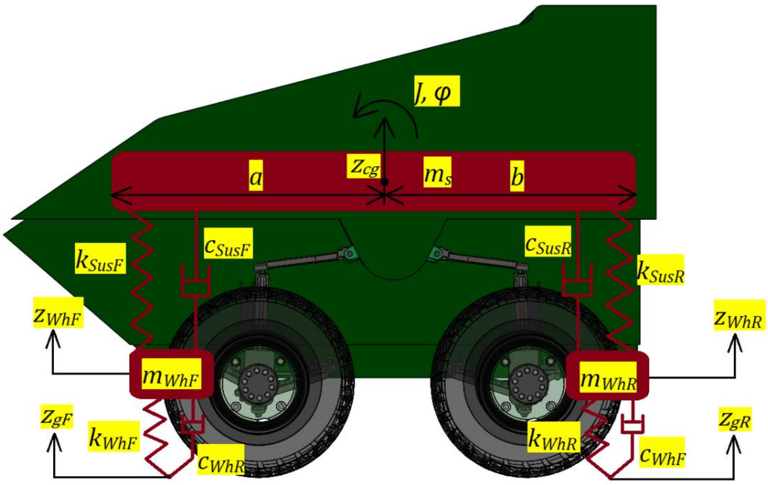


Fig. 1 Quarter car linear passive suspension system

For the validation of the mathematical modeling, state space approach might be utilized. From the equations above, (1), (2), (3), (4) the state space equations below, (5) and (6) are obtained.

$$\dot{X}=A\cdot X+B\cdot U;\tag{5}$$

$$Y=C\cdot X+D\cdot U.\tag{6}$$

Assuming:

$$A_1=\begin{pmatrix} 0 & 1 & 0 & 0\\ \dfrac{-k_{SusF}-k_{SusR}}{m_s} & \dfrac{-c_{SusF}-c_{SusR}}{m_s} & \dfrac{k_{SusF}\cdot a-k_{SusR}\cdot b}{m_s} & \dfrac{c_{SusF}\cdot a-c_{SusR}\cdot b}{m_s}\\ 0 & 0 & 0 & 1\\ \dfrac{-k_{SusF}\cdot a-k_{SusR}\cdot b}{J} & \dfrac{c_{SusF}\cdot a-c_{SusR}\cdot b}{J} & \dfrac{k_{SusF}\cdot a^2-k_{SusR}\cdot b^2}{J} & \dfrac{-c_{SusF}\cdot a^2-c_{SusR}\cdot b^2}{J} \end{pmatrix};$$

$$\dot{X}=\begin{pmatrix} dX_1\\ dX_2\\ dX_3\\ dX_4\\ dX_5\\ dX_6\\ dX_7\\ dX_8 \end{pmatrix};\ X=\begin{pmatrix} X_1\\ X_2\\ X_3\\ X_4\\ X_5\\ X_6\\ X_7\\ X_8 \end{pmatrix};\ B=\begin{pmatrix} 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ \dfrac{k_{WhF}}{m_{WhF}} & 0\\ 0 & 0\\ 0 & \dfrac{k_{WhR}}{m_{WhR}} \end{pmatrix};\ U=\begin{pmatrix} z_{gF}\\ z_{gR}\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0 \end{pmatrix};\ Y=\begin{pmatrix} Y_1\\ Y_2\\ Y_3\\ Y_4\\ Y_5\\ Y_6\\ Y_7\\ Y_8 \end{pmatrix};C=\begin{pmatrix} 1\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0 \end{pmatrix}^T;\ D=\begin{pmatrix} 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0 \end{pmatrix}^T;\ A=\begin{pmatrix} A_1 & A_2\\ A_3 & A_4 \end{pmatrix};$$

$$A_2 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ \frac{k_{SusF}}{m_s} & \frac{c_{SusF}}{m_s} & \frac{k_{SusR}}{m_s} & \frac{c_{SusR}}{m_s} \\ 0 & 0 & 0 & 0 \\ \frac{-k_{SusF}\cdot a}{J} & \frac{-c_{SusF}\cdot a}{J} & \frac{k_{SusR}\cdot b}{J} & \frac{c_{SusR}\cdot b}{J} \end{pmatrix};$$

$$A_3 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ \frac{k_{SusF}}{m_{WhF}} & \frac{c_{SusF}}{m_{WhF}} & \frac{-k_{SusF}\cdot a}{m_{WhF}} & \frac{-c_{SusF}\cdot a}{m_{WhF}} \\ 0 & 0 & 0 & 0 \\ \frac{k_{SusR}}{m_{WhR}} & \frac{c_{SusR}}{m_{WhR}} & \frac{k_{SusR}\cdot b}{m_{WhR}} & \frac{c_{SusR}\cdot b}{m_{WhR}} \end{pmatrix}; A_4 = \begin{pmatrix} 0 & 1 & 0 & 0 \\ \frac{-k_{WhF}-k_{SusF}}{m_{WhF}} & \frac{-c_{WhF}-c_{SusF}}{m_{WhF}} & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & \frac{-k_{WhR}\cdot k_{SusR}}{m_{WhR}} & \frac{-c_{WhR}\cdot c_{SusR}}{m_{WhR}} \end{pmatrix},$$

where, $X_1 = z_{cg}, X_2 = \dot{z}_{cg}, X_3 = \varphi, X_4 = \dot{\varphi}, X_5 = z_{WhF}, X_6 = \dot{z}_{WhF}, X_7 = z_{WhR}, X_8 = \dot{z}_{WhR}$, A is the matrix of state, B and C are input and output matrices, D is the matrix of direct transmission. With MATLAB and Simulink, a curve of displacement in Fig. 4 was created.

4. MBS Model

With utilization of ADAMS, from MSC Software, a MBS model has been suggested. Presented in Fig. 3 is the layout of aforementioned model. Problematic parts, like appropriate connectors and tire models were solved with knowledge from [1] and [5]. The model has 4 DOF and the input to the wheels is given by road model.

The road model (Fig. 2) was created in ADAMS Car, in road builder, with methods from [6]. To accomplish the smooth bump, the road points in corresponding axis direction were generated from the Eq. (7).

$$bump = \frac{e^{\frac{x^2}{\left(x^2-L^2\right)}}}{7.2}, \tag{7}$$

where x is symmetrical distance, equally divided between the start-point and end-point of the curve, L is the "diameter" of the bump, and the expression is divided by 7.2 for achieving the maximal height of the bump of 14 cm.

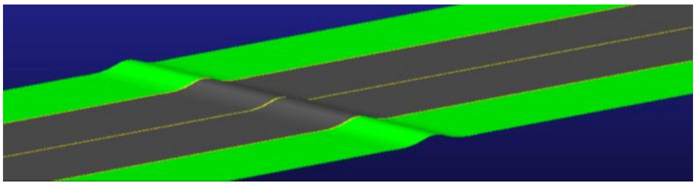


Fig. 2 Road model

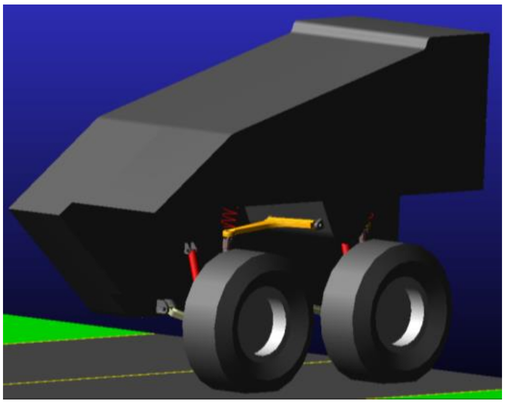


Fig. 3 Quarter car model in the Adams software

Input data received by wheels of mathematical model were exactly same to the front wheel, data to rear wheel were delayed. The delay is related to traveling speed, which in this case was 1.5 m/s. With the distance between wheels set to $(a + b) = 1.5$ m, the delay is exact one second.

All of the necessary properties of individual parts, for example weights, moment of inertia, positions of point of interest, centres of gravity, were computed by CAD software, based on the 3D model. Rest of the characteristics were set to a specific values based on the knowledge from [2]. For this particular model, no bushings were used. According to reality, at least 4 should be used for each suspension unit, however it is nearly impossible to acquire valid properties- 2 matrices with 6x6 dimensions, one for stiffness and one for damping characteristic.

Due to prevention of the unwanted excitation, emerged from the acceleration of the vehicle and contact forces between road and wheels, the friction coefficient of the road is 0 and road is moving against the vehicle. This was achieved by using a simple translational joint between the ground and road model, along with joint motion.

5. Comparison of Outcomes- Displacement of the Centre of Gravity

Presented in Fig. 4 is the main result of this paper. The differences which occur in the beginning of the orange curve are mainly caused by the small step displacement in the road, transition between flat road and bump is not smooth enough.

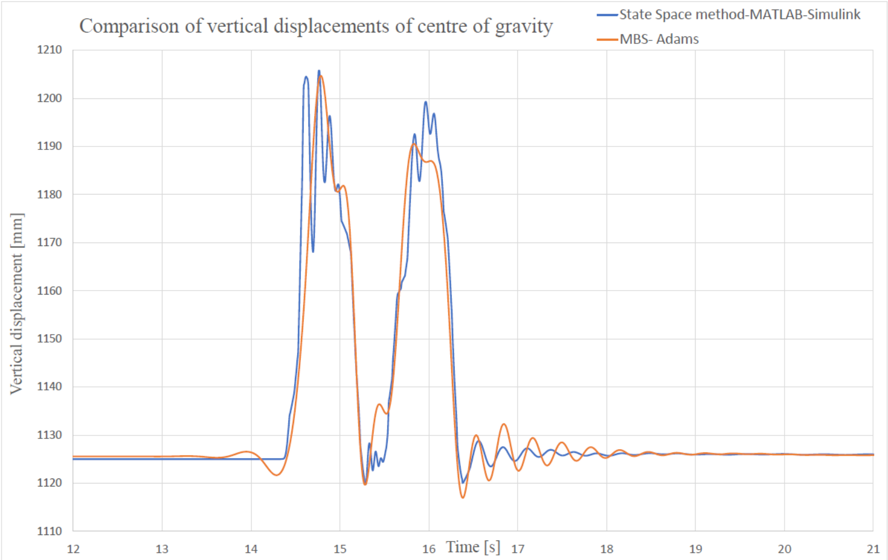


Fig. 4 Main outcomes of the paper

Also, a wheel following the road seems to respond better than function input to the mathematical model. During the simulation in Adams, for a few milliseconds the wheel lost contact with a road, so the following impact excited the vehicle even more. The last part of the curves might be caused by movement of the wheel. Due to suspension layout, the wheel might excite itself and additional peaks must be damped by tire properties. Which are for MBS model better, in State Space method there is only the vertical stiffness and damping, in MBS the stiffness and damping are present in all 3 axis.

6. Comparison of Suspension Layouts

The vehicle utilizes the modified layout of the wishbones, bottom wishbone is in ordinary position, while the front wishbone is in modified state- vertical height from the ground is different in the inner and outer mounting point and whole mounting is perpendicular to bottom mounting. During the deflection of the wheel, its movement is in all 3 axis, so rather complicated. This solution is used due to its engineering aspects. However it might be interesting to see the differences of these two solutions in case of overcoming the obstacles.

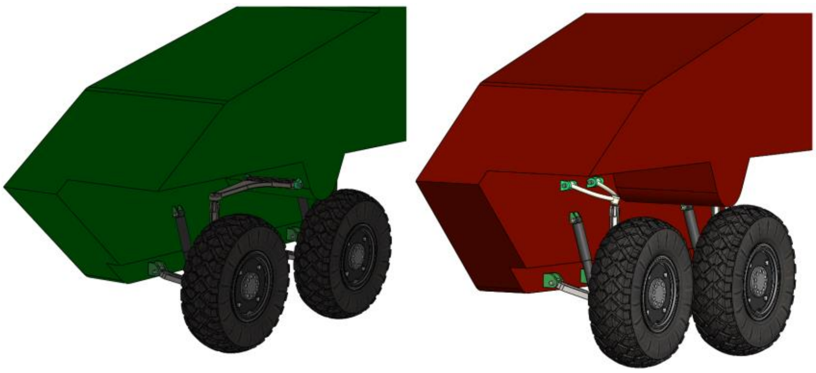


Fig. 5 Both layouts of the suspension, green hull pictures modified layout, red pictures ordinary SLA

As can be seen in Fig. 6, the initial value of vertical height is different in ordinary layout. This is caused by lack of stiffness in the springs, due to changed position of the wishbone, but the spring remained in the same place. In modified case, the spring is positioned and oriented directly against the wishbone´s movement, in ordinary Short Long Arm (SLA) layout, the orientation and position of the spring is far from ideal.

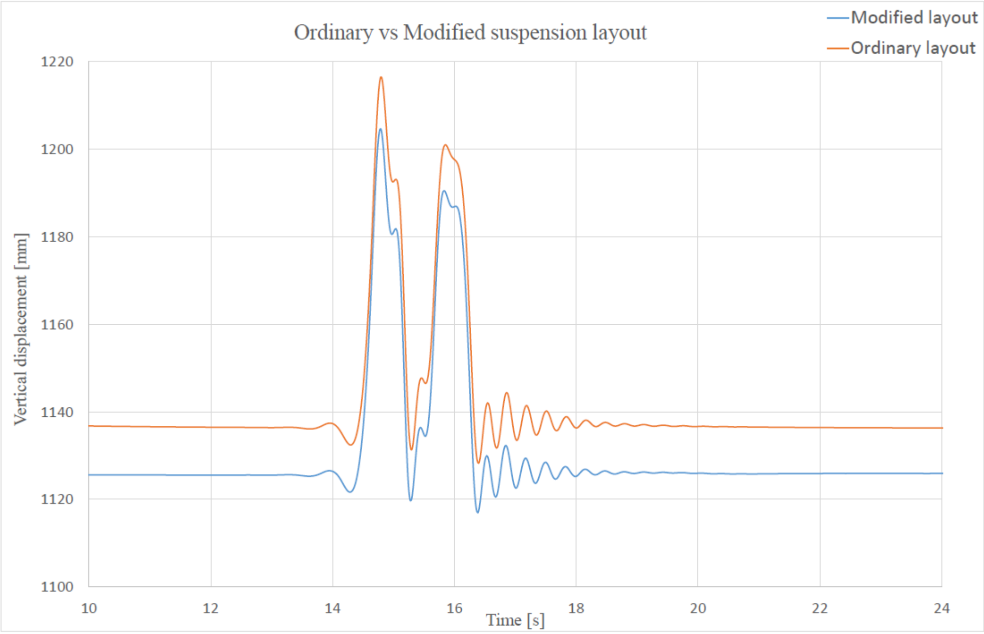


Fig. 6 Comparison of both layouts in case of vertical displacement

Therefore the springs are stiffer, by nearly one additional third of the value, meaning that in state of equilibrium the vertical position of centre of gravity is slightly higher. If a constant of 11 mm (difference between layouts) is added to the height of modified layout, both curves are almost completely overlaid. Naturally, due to higher spring stiffness, the rear wheel is more excited after its impact, but the differences are barely visible. There are no other major changes in the behavior of the vehicle.

In the picture below – Fig. 7, magnitudes of front wheels in both layouts can be seen. With adding a constant to modified layout, both curves are almost overlaid. The constant serves as an initial condition because in SLA layout, the initial wheel position is slightly different. With upright attached by two ball joint between the wishbones and steering link attached to the rear part of the uprights, we can see minimal changes in wheel travel. Position and orientation of upper wishbone, from modified layout, are both very well designed. However, in my opinion, in case of steering under the deflection of the wheel, the differences will be higher.

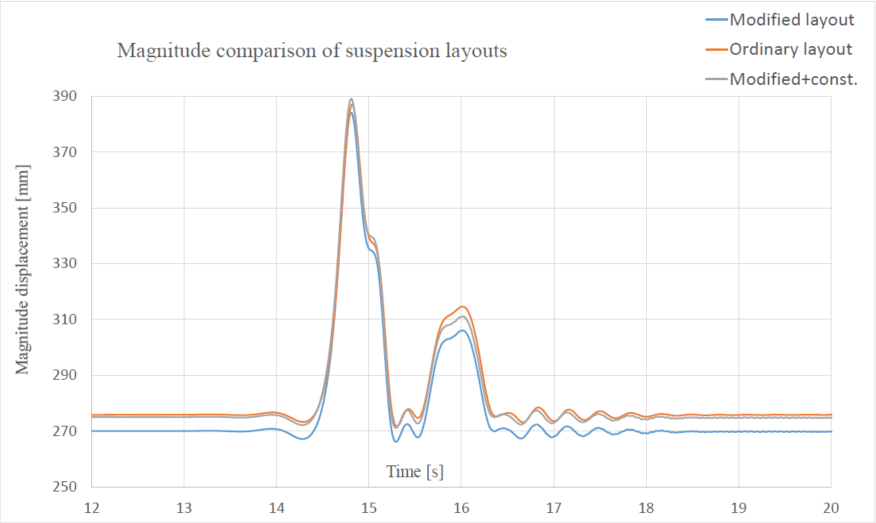


Fig. 7 Magnitudes of displacement for both suspension layout

7. Conclusion

Presented in this paper are two possibilities of modeling the vehicle suspension. State Space method and Multi

Body System approach. As seen in Fig. 4, there are no major differences, or differences which were not justified. So both models are successfully validated, therefore the next aim is half car model of this particular vehicle.

In the last part of the paper the different suspension layouts were compared, however with no major changes- in case of overcoming the obstacle and topic of this paper. It will be interesting to see similar study, but with steerable wheels, and steering under the deflection of the wheel- for both of these layouts.

For the future studies, two information arose: utilization of bushings needs to be considered, along with smoother transition between flat road and bump- or any kind of obstacle.

Acknowledgements

The presented paper has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development, K-202, Department of Combat and Special Vehicles, University of Defence, Brno.

References

1. **Blundell, M.; Harty, D.** 2015. The Multibody Systems Approach to Vehicle Dynamics. United Kingdom: Elsevier, 755 p.
2. **Fancher, P.S.; Ervin, R.D.; Winkler, Ch.B.; Gillespie, T.D.** 1986. A Factbook of The Mechanical Properties of The Components for Single-unit and Articulated Heavy Trucks. Michigan: UMTRI, 202 p.
3. **Gorelov,V.A.; Komissarov, A.I.; Miroshnichenko, A.V.** 2015. 8x8 Wheeled Vehicle Modeling in a Multibody Dynamics Simulation Software. Procedia Engineering 129: 300-307.
4. **Trikande, M.W.; Jagirdar, V.V.; Sujithkumar S.** 2014. Evaluation of semi-active suspension control strategies for 8x8 armoured vehicle using stochastic road profile inputs, IFAC Proceedings, Kanpur 47: 941-948.
5. Using the PAC2002 Tire Model [online cit.: 2018-06-28].
   Available from: http://mech.unibg.it/~lorenzi/VD&S/Matlab/Tire/tire_models_pac2002.pdf
6. Designing a track in Adams/Car [online cit.: 2018-06-29].
   Available from: http://www.me.ua.edu/me364/Student_Version/Building_a_track_Tutorial.pdf

Proceedings of 22nd International Scientific Conference. Transport Means. 2018.

Impacts of Threats on the Functionality of the Transport Critical Infrastructure

M. Titko

University of Žilina, Faculty of Security Engineering, Department of Crisis Management, Ul. 1. mája 32, 01026 Žilina, Slovak Republic, E-mail: Michal.Titko@fbi.uniza.sk

Abstract

The objective of this article is to assess impact of threats on the functionality of the transport critical infrastructure. In order to carry out such an assessment we propose to use (1) threat analysis and (2) vulnerability analysis of a particular critical infrastructure element. In both cases, the analysis consist from identification of relevant factors and their evaluation in form of weighted multi-criteria assessment. As the result the approach for identification of the most important threats with related possible level of transport critical infrastructure disruption is proposed. It can further serves as a basis for probability and consequences analysis of such a disruption. The conducted assessment of threats severity provides a structural approach to the problem and highlights the diversity of threats and its possible influence on the functionality of critical infrastructure.
KEY WORDS: *threats, risk assessment, transportation, critical infrastructure*

1. Introduction

The recent years have been several examples of the transportation network (TN) being affected by extreme natural hazards such as the earthquake in Kobe (1995) and hurricane Katrina (2005) as well as man-made threats such as terrorist attacks (Madrid 2004, London 2005) and war conflicts, industrial accidents [1] or combination of different hazards (natural and technological) as Fukushima (2011). Such events can cause the disruption or failure of the TN elements and that can result in the worst scenarios into (1) the significant distortion of political and economic processes of the state [2-5], (2) into the disruption of the security and public order [2, 5], (3) into the disruption of the operational capability of the armed forces [2] or (4) it can significantly endanger the lives and health of the population [2-6]. These consequences are assumed to be higher with increasing importance of a particular TN element. It results in identification of the notion of critical infrastructure (CI) – a subset of the transportation network that is of the particular importance and interest.

As indicated, the TN and especially the CI, is important to serve the national priorities and moreover, reliability and performance of TN have significant influence on services which are provided by the other sectors, and in many instances TN spans these sectors [7]. Therefore the understanding of the TN weak points and its resilience to all kind threats is important in general and in particular critical for the national security.

Analysis of TN should always be viewed in a broader context – with relation to geo-spatial, industrial, social context, etc. This can be reflected using the risk management framework with common parts [8]: establish the context, risk identification, risk analysis, risk evaluation, risk treatment, monitoring and review, and communication and consultation. In order to assess the above mentioned societal impacts and impacts to national security due to the TN element functionality loss, it is necessary in the first place to determine the level of disruption caused by threats on the TN element. In this work we focus especially on this part by using the all-hazard approach including (1) the threat severity analysis and (2) the CI element vulnerability analysis. In order to perform these analyses it should be clear what will be understood as a failure or TN functionality disruption. For that purpose the categorization of a threat impact on the TN element functionality in form of Disruption rate will be also proposed.

2. Background - Failure of the Transport Infrastructure Element

The key function of a transportation network is to provide means to move people and goods between the origin and destination, usually by optimizing the transport costs. There are several reasons (mostly external – disasters, accidents, deliberate actions, etc. or internal - maintenance and repairs) which may disrupt the core function of the system. The rate of the disruption or functionality loss is dependent on the threat type, its intensity, the severity and duration of repairs as well as on structural characteristics of an element itself and capability to deal with such a situation. In ordinary cases TN has certain capacity to absorb some degree of disruptions. However, larger scale events (e.g. extreme weather events) or deliberate threats, may cause more severe impacts on transport infrastructure, including its partial [9, 10] or total [10] failure.

Transportation network element failure may be defined as loss of a structural component, loss of an element's basic functionality, a catastrophic element collapse, or any damage condition in between [11]. Generally, it can be define also in terms of reliability of an element to perform its main function [3]. As an important characteristic of the CI element to perform its function is considered its capacity [5]. The possible loss of that quantity, can be consider as a

failure measure. Basically, the reduction or the loss of capacity can be caused by (1) physical (structural) damage or physical obstacles on the road or by (2) traffic distribution changes. Therefore, we assume two main groups of the impacts on the functionality of the CI elements:

1. direct impact, which we understood as the impact on CI element capacity;
2. indirect impact – change in traffic distribution resulting in effects on demand on a TN element or the TN as whole.

For the purpose of the paper only direct impact on the CI element capacity will be taken into consideration. As it was mentioned our scope are all kinds of threats, especially disasters, extreme weather events, accidents as well as man-made threats. There are significant differences between impacts of the threats e.g. the bridge scour due to a severe flood, earthquake damages, heavy snow load, winter storm, traffic accident, etc. To address these differences of direct impact of the threats on capacity or functionality loss the categorization in the form of *Disruption Rate* is proposed. Disruption rate levels are assumed as follows:

- nominal or no limitation – managing the situation by common means, maintenance and management; comparing the maximum construction capacity and the utilization rate of the transportation element - some TN elements have a reserve that guarantees the required capacity despite the disaster;
- low operability limitation – effect on traffic capacity is low – remaining capacity is sufficient to handle traffic demand with some minor delays resulting from the reduced speed limit, rescue activities, etc.;
- significant operability limitation – traffic demand is not fully satisfied or it is satisfied with significant delays – there are delays due to obstacles (debris) on the transport element or the transport route conditions; for some types of vehicles (e.g. trucks) can be transition temporarily disabled – the alternative routes are applied (redundancy take place);
- partial collapse – complete loss of the capacity – due to structural damages (on surface, static, etc.) the use of the element is forbidden and long-lasting disruption is assumed;
- total collapse – complete loss of the capacity – in the worst scenarios destruction of an element without recovery option is assumed.

3. Disruption Rate - The Direct Impact on the Functionality of the Transport Critical Infrastructure

The *Disruption rate* is assumed to consist from identification and evaluation of two groups of relevant factors. First group of factors is assumed to characterise the threats severity (in form of the threat rate) and the second one is assumed to characterise the vulnerability (in form of the vulnerability rate) of the transport elements. These factors reflect particularities of the threats as well as the transport CI elements under analysis. Moreover, these factors may influence the overall rate of risk. Into consideration are taken construction parameters of the CI elements as well as the safety and security preventive measures already implemented which can reduce the threat level and/or the CI elements vulnerability. By combination of threat severity and vulnerability rate it is possible to determine the expected functionality disruption level of the particular CI element.

3.1. Threat Analysis

The threat rate is a latent feature of the system (object, subject, or event) and its components which cause unexpected impacts that threaten the safety, the stability and serviceability of a system, or even his surroundings [12]. In order to address the particularities of the threats, form of action, intensity, severity, etc., as the suitable factors were identified these ones:

- destructiveness – F_{Des};
- deliberateness – F_{Del};
- activatability – F_{Ac};
- duration – F_{Dur}.

Each factor is assumed to be scored based on the five-level scale, from 1 to 5, with increasing value indicates more dangerous threat for the transport CI elements.

Destructiveness (the ability of the threat to cause damage) is associated with a particular threat, its type, mode of action, extent, and especially with ability to cause damage. It also depends on the environment and the external conditions in which it operates. The categorization of the threat ability to cause damage is shown in the rating scale (Table 1).

Table 1

The categorization of the ability of the threat to cause damage

The destructiveness level	F_{Des} value
Very low - the ability to cause damage is very low	1
Low - the ability to cause damage is low	2
Medium - the ability to cause damage is average	3
High - the ability to cause damage is high	4
Very high - the ability to cause damage is very high	5

Deliberateness examines the level of intention and interest in initiating a threat to the CI element. This characteristic distinguishes the intent of a threat activation. Therefore, to the natural threats is assigned a minimum level

and to the terrorism and the war conflict is assigned substantially higher level. The categorization of the deliberateness factor is shown in the rating scale (Table 2).

Table 2

The categorization of the deliberateness

The deliberateness level	F_{Del} value
None - the threat has no intention of endangering the element	1
Low - activation of the threat is intentional (the element is not the priority – only minimal operational consequences can be expected)	2
Medium - activation of the threat is intentional, but the element is not the priority (nevertheless operational disruption can be expected)	3
High - activation of the threat is intentional, but the element is not the priority (nevertheless structural damage can be expected)	4
Very high - the primary intent of initiating the threat is the element destruction	5

Activatability represents the time that is required to activate a threat - the longer activation time, the less dangerous a threat is. This is dictated by the possibility to prepare for a development of the threat destructive potential and its negative effects. However, this claim does not apply generally, rather to the threats of unintentional character, e.g. in the case of a war conflict, it is not reasonably possible to handle this threat without any consequences. It results from its destructive power and limited resources to deal with such situations (these could also be inefficiently used). There is usually relatively enough time for preparation (in principle, the war is preceded by a state of war), but determinant is the force, the readiness of the adversary, which could be hardly influenced. The categorization of the activatability factor is shown in the rating scale (Table 3).

Table 3

The categorization of the activatability (adapted from [13])

The activatability level	F_{Ac} Value
Very low - the threat activation is assumed in months; it is possible to prevent the influence of a threat against the element	1
Very low - the threat activation is assumed in weeks; it is possible to prevent the influence of a threat against the element; it is almost entirely possible to prevent the influence of a threat against the element	2
Medium - the threat activation is assumed in days; it is partially possible to prevent the influence of a threat against the element	3
High - the threat activation is assumed in hours; it is hardly possible to prevent the influence of a threat against the element	4
Very high – immediate (sudden) threat activation is assumed; it is not possible to prevent the influence of a threat against the element	5

Duration represents the anticipated time period of a threat effects on the transport. At the same time, it includes the time necessary to restore the required operational level of the transport element. The categorization of the duration factor is shown in the rating scale (Table 4).

Table 4

The categorization of the threat duration

The threat duration	F_{Dur} Value
Very short duration of negative impacts (from several hours to days)	1
Short duration of negative impacts (from several days to weeks)	2
Medium-term duration of negative impacts (from several weeks to months)	3
Medium-term duration of negative impacts (from several months to years)	4
Extremely long duration of negative impacts (several years)	5

Determination of weights of individual threat factors

The individual factors do not have the same share on the overall threat rate and therefore the importance of the individual factors should be taken into account. The weights of the factors were determined using the PAPRIKA method, using the 1000minds software, which uses the principle of the method in the software environment (Table 5).

Table 5

The weights of the threat factors

The threat factors	Weight
Destructiveness (F_{Des})	0,503
Deliberateness (F_{Del})	0,128
Activatability (F_{Ac})	0,070
Duration (F_{Dur})	0,299

Determining the threat rate

The overall threat rate (T_O) is calculated based on the assigned value of individual factors. They are multiplied by the corresponding weights, and then all are summed together (Eq. 1).

$$T_O = 0{,}503 \cdot F_{Des} + 0{,}128 \cdot F_{Del} + 0{,}070 \cdot F_{Ac} + 0{,}299 \cdot F_{Dur} \,. \tag{1}$$

By specifying the minimum (1) and maximum (5) threat level (it is based on five-point scale for individual factors evaluation), it is possible to create intervals and categorise the threats according to its overall value (Table 6). This categorization is necessary for determination of the threat severity.

Table 6

The categorization of the threat rate

Threat rate category	**Threat rate intervals**
Very low	<1 – 1,8>
Low	(1,8 – 2,6>
Medium	(2,6 – 3,4>
High	(3,4 – 4,2>
Very high	(4,2 – 5>

3.2. Vulnerability Analysis

Vulnerability is a complex feature that reflects weaknesses of the system and its reduced resistance to possible damage, destruction, or disruption of its function [14-16]. Therefore, a possible impact of the threats on the CI functionality can be taken into consideration within vulnerability determining. The nature (types) of the CI element (bridges, roads, or tunnels) points to significant differences in their vulnerability to a certain threat. By identifying the appropriate characteristics of the vulnerability, it is possible to better describe the possible negative effects on a particular CI element. The following factors have been identified as suitable for assessing the vulnerability level of the CI elements.

- sensitivity – F_S;
- accessibility/exposure – F_{Acc} (adapted from [12]);
- assurance – F_{As};
- attractiveness – F_{At}.

Each vulnerability factor is scored similarly as the threat severity factors, from 1 to 5, with increasing value indicates more vulnerable (or less resilient) transport CI elements.

Sensitivity is the susceptibility of the element to be (1) functionally disturbed or (2) physically damaged by a particular threat. This characteristic is related to the ability of the transport element (or network) to manage the negative effects of specific threat by its construction characteristics as robustness, quality of materials used, construction age, etc.). The CI elements should have the features and design assumptions for smooth managing of the negative effects. The categorization of the sensitivity factor is shown in the rating scale (Table 7). Here it is necessary to distinguish between physical damage and functional (operational) disruption. While physical damage can at the same time cause the operational difficulties, on the contrary, the operational disruption does not necessary mean also structural damage (e.g. flooded road does not have to be inevitably damaged). Example: road in mountain area is highly susceptible to the effects of snowstorm, it could be given value 4 or 5; on contrary for flood threat it could be given value 1.

Table 7

The categorization of the sensitivity factor

The level of sensitivity	**F_S Value**
The susceptibility of the element to be functionally disturbed by a particular threat is very low. Due to the design features is extremely difficult to damage or destroy the element.	1
The susceptibility of the element to be functionally disturbed by a particular threat is low. Due to the design features is very difficult to damage or destroy the element.	2
The susceptibility of the element to be functionally disturbed by a particular threat is on medium level. Due to the design features is difficult to damage or destroy the element.	3
The high susceptibility level of the element to be functionally disturbed by a particular threat. Due to the design features is not difficult to damage or destroy the element.	4
The very high susceptibility level of the element to be functionally disturbed by a particular threat. The design features are not sufficient to prevent damage or destruction of the element.	5

Accessibility (exposure) is the level of simplicity to which may be an element jeopardized by a threat. In the case of deliberate attacks on a particular element, the difficulty to access to the asset must be taken into account. In

context of natural threats as relevant qualities are assumed the position of the object, flood area, tectonic area, possible landslides in the area, etc. [13] – it can be understood also as **exposure** factor. The categorization of the accessibility factor is shown in the rating scale (Table 8).

Table 8

The categorization of the accessibility factor

The level of accessibility/exposure	**F_{Acc} Value**
Very low - the threat have no access to the element; the element is not exposed to the threat.	1
Low - it is very complicated to overcome barriers (protection measures) to get access to the element; the element is exposed to the threat at minimum level.	2
Medium - it is complicated to overcome barriers (protection measures) to get access to the element; the element is partially exposed to the threat.	3
High - it is basically easy to overcome barriers (protection measures) to get access to the element; the element is highly exposed to the threat.	4
Very high - the element is in an accessible environment for the threats, there are no barriers (protection measures) to overcome; the element is completely exposed to the threat.	5

Assurance - represents the level of security of the element against the concrete threat in terms of its (1) protection (protection mode - during the State of Emergency and State of Exception) or in terms of (2) defence (defence mode - War, State of Ware and partially in the State of Exception). It includes monitoring, mitigation actions (flood dams, strengthening slopes, etc.), physical protection (e.g. guard services) or defence, use of other security means, use of military technologies, etc. The categorization of the assurance factor is shown in the rating scale (Table 9).

Table 9

The categorization of the assurance factor

The level of assurance	**F_{As} Value**
Very high assurance level – all necessary preventive measures against threat are in place with corresponding human and material resources prepared for the worst case scenario	1
High assurance level - all necessary preventive measures against threat are in place with corresponding human and material resources prepared for the common disaster scenario	2
Medium assurance level - preventive measures against threat are partially in place with corresponding human and material resources prepared for the low scale disaster scenario	3
Minimal assurance level – only some preventive measures against threat are in place with minimum human and material resources support	4
Very low assurance level – there are no preventive measures against the threats in place; there is a lack of human and material resources for any type of disaster	5

Attractiveness refers only to the intentional threats and expresses the degree to which the element attracts the potential attacker. The objective of these intentional attacks vary based on the attacker type. We differ two main types: (1) terrorist groups and (2) military groups. For terrorist groups are attractive mainly transport nodes with high concentration of people and for the military groups are the enemy's priority objectives mainly bridges, tunnels and highways (also loading stations) due to high recovery time and type of transported commodities (the higher and the longer element, the higher recovery time). Also the importance for mobility of the armed forces is taken into consideration. For unintentional threats, levels of attractiveness are minimal, for example, natural phenomena do not bring initiative to cause damage. The categorization of the attractiveness factor is shown in the rating scale (Table 10).

Table 10

The categorization of the attractiveness factor

The level of attractiveness	**F_{At} Value**
Very low - the unattractive target for potential attackers	1
Low - the minimal advantages (goals) for actors are obtain/fulfilled (terrorist targets: a small number of affected people; military targets: short bridges, roads of III. category)	2
Medium - the minor advantages (goals) for actors are obtain/fulfilled (terrorist targets: a considerable number of affected people; military targets: medium long bridges, short tunnels, roads of II. category)	3
High - the great advantages (secondary goals) for actors are obtain/fulfilled (terrorist targets: a high number of affected people; military targets: high and long bridges, medium long tunnels, roads of I. category, minor cargo stations)	4
Very high - primary goals for actors are fulfilled (terrorist targets: an enormous number of affected people; military targets: the biggest and the most important bridges, tunnels, highways, and cargo stations)	5

Determination of weights of individual vulnerability factors

The individual factors of vulnerability do not have the same share on the overall vulnerability rate and therefore the importance of the individual factors should be assessed. The weights of the factors were determined using the PAPRIKA method, using the 1000minds software, which uses the principle of the method in the software environment (Table 11).

Table 11

The weights of the vulnerability factors

Vulnerability factors	**Weight**
Sensitivity (F_S)	0,261
Accessibility (F_{Acc})	0,202
Assurance (F_{As})	0,231
Attractiveness (F_{At})	0,307

Determining the vulnerability rate

The overall vulnerability rate **(V_{PECI})** of potential element of the CI (PECI – "potential" is used due to fact that the concrete CI elements are mainly classified as confidential or secret) is calculated based on the assigned value of individual factors. They are multiplied by the corresponding weights, and then all are summed together (Eq. 2).

$$V_{PECI} = 0{,}261 \cdot F_S + 0{,}202 \cdot F_{Acc} + 0{,}231 \cdot F_{As} + 0{,}307 \cdot F_{At} \,. \tag{2}$$

By specifying the minimum (1) and maximum (5) vulnerability rate (it is based on five-point scale for individual factors evaluation), it is possible to create intervals and categorise the potential CI element according to its overall value (Table 12). This categorization is necessary for determination of vulnerability level of particular CI elements.

Table 12

The categorization of the CI elements vulnerability

Vulnerability category	**Vulnerability intervals**
Low	<1 – 1,8>
Very low	(1,8 – 2,6>
Medium	(2,6 – 3,4>
High	(3,4 – 4,2>
Very high	(4,2 – 5>

3.3. Determining the Disruption Rate

The resulting level of *Disruption rate* is determined based on the threat rate and vulnerability rate. For the final evaluation of the Disruption rate a Severity matrix of potential impact (or Disruption rate matrix) was used which results into five scale categorization, according to description of Disruption rate categories in previous chapter. Each level expresses the possible impacts of selected threat on the serviceability of selected CI element from minimal influence to long-term serviceability loss (see matrix on Fig. 1).

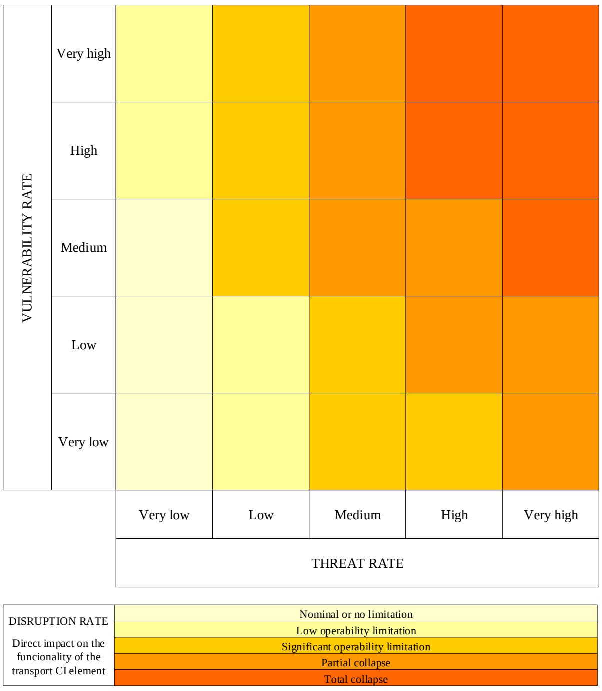


Fig. 1 Disruption rate matrix

The level of the CI functionality disruption indicates the level of possible consequences on the society and national security. In order to reduce the number of the threats for further analysis (especially for societal impact analysis) the assessor can exclude the threats with low potential to cause negative impact based on the results of Disruption rate matrix. For further analysis are important especially the threats with potential to cause significant operability limitation on the CI element, partial as well as total collapse.

4. Conclusion

In order to assess societal impacts arising from disruption of the TN element functionality it is necessary to determine the level of such a disruption. For that purpose analysis of the threats endangering the TN element as well as the vulnerability analysis of the TN element was proposed based on the identification of relevant factors. It results into Disruption rate assessment in form of Disruption rate matrix. By understanding and implementation of such an assessment can responsible authorities modify protection measures or apply new ones and increase the security and safety level of the TN elements and whole society as well. The proposed approach is assumed to be used within the risk management, mitigation measures planning, creation of the security plans, etc. It can help to government, policy makers, crisis managers or critical infrastructure operators to take adequate decisions and adapt relevant policy to reduce threat or/and vulnerability rate.

The conducted assessment provides a structural approach to the problem of possible influence on the CI functionality and highlights the diversity of threats and vulnerability analysis importance. The approach is intended to be applied to the CI elements rather than the TN as whole. This is dictated by practical consideration because burden placed on the assessors should be limited. The approach is modifiable to other CI sectors as well.

If we omit the possibility of synergic or domino effect, the occurrence of multiple events at once is highly unlikely. From that reason we assume to assess each threat separately. We claim, that the approach is after modification and amendment suitable also for consideration of cascading effects, but further research is required. Similarly, the CI elements are assumed to be analysed separately. To address also indirect impact or to address combination of direct and indirect impact of the threats on the transport CI at once, it seems to be suitable to use other methods such as influence diagrams, network analysis, etc. and this our intention do so in further research.

Acknowledgements

This work was supported by Scientific Grant Agency of Slovak republic within the project no.1/0240/15 “Process model of critical infrastructure safety and protection in the transport sector”.

References

1. **Zánická Hollá, K.; Ristvej, J.; Šimák, L.** 2010. Systematic method of risk assessment in industrial processes, In: Risk analysis VII: simulation and hazard mitigation - Southampton: WIT Press - ISBN 9781845644747 - WIT transaction on information and communication technologies; v. 43. - ISSN 1746-4463. DOI: 10.2495/RISK100111
2. **Šimák, L.; Dvořák, Z.; Gašpierik, L.; Kampová, K.; Reitšpís, J.; Seidl, M.; Svetlík, J.** 2012. Protection of critical infrastructure in sector transportation. University of Žilina, Žilina: EDIS. p. 180.
3. **Taylor, M.A.P.; D'este, G.M.** 2003. Concepts of network vulnerability and applications to the identification of critical elements of transport infrastructure. 26th Australasian Transport Research Forum. Wellington. Available at: http://search.ror.unisa.edu.au/media/digital/open/9915913443501831/12143366150001831/13143375830001831/pdf
4. **Loveček, T.; Ristvej, J.; Šimák, L.** 2010. Critical Infrastructure Protection Systems Effectiveness Evaluation, Journal of homeland security and emergency management. ISSN 1547-7355. Vol. 7, No. 1.
5. **Dvořák, Z.** 2014. Crisis Management Decision Support System in Railway Infrastructure Company. Proc. of the International Conference - Transport Means. Kaunas University Technology, Kaunas.
6. **Leitner, B.; Luskova, M.; O'Connor, A.; Van Gelder, P.** 2015. Quantification of impacts on the transport serviceability at the loss of functionality of significant road infrastructure objects. In: Communications. Vol. 17, Issue 1
7. **Rinaldi, S.M.; Peerenboom, J.P.; Kelly, T.K.** 2001. Identifying, understanding, and analyzing critical infrastructure interdependencies, In: IEEE Control Systems 21: 11-25.
8. **Gjerdrum, D.; Mary, P.** 2011. The New International Standard on the Practice of Risk Management – A Comparison of ISO 31000:2009 and the COSO ERM Framework. Risk Management. Issue 21. Available at: <https://www.soa.org/Library/newsletters/risk-management-newsletter/2011/march/jrm-2011-iss21-gjerdrum.pdf>
9. **Titko, M.; Zagorecki, A.** 2013. Modelling Vulnerability of Critical Infrastructure of Transportation Network using Influence Diagrams. In: Communications. Vol. 4, Issue 1, 2013. ISSN 1335-4205.
10. **Cook, W.** 2014. Bridge Failure Rates, Consequences, and Predictive Trends. Utah State University, Logan, Utah. Dissertation thesis. 116 p.
11. **Lee, G.C.; O'Connor, J.; Qi, J.C.; Wang, Z.Q.** 2008. Development of a Bridge Failure Database. Fourth US-Taiwan Bridge Engineering Workshop. Princeton, New Jersey.
12. **Šimák, L.; Horáček, J.; Novák, L.; Németh, Ľ.; Míka, V.** 2006. Terminologický slovník krízového riadenia (Terminological dictionary of crisis management). Žilina, ISBN 80-88829-75-5. pp 44.
13. **Řehák, D.; Cígler, J.; Němec, P.; Hadáček, L.** 2013. Kritická infrastruktura elektroenergetiky - určování, posuzování a ochrana (Critical Infrastructure in the Energy Sector – identification, assessment and protection). SPBI spektrum XXI.
14. **Flanagan, B.E.; Gregory, E.W.; Hallisey, E.J.; Heitgerd, J.L.; Lewis, B.** 2011. A Social Vulnerability Index for Disaster Management, Journal of Homeland Security and Emergency Management, Vol. 8, Iss. 1, Article 3.
15. **Birkmann, J.** Measuring vulnerability to natural hazards: towards disaster resilient societies, Tokyo, Japan: United Nations University Press, 2013, ISBN 978-92-808-1202-2. Section Political Sciences
16. **Husdal, J.** 2004. Reliability and vulnerability versus cost and benefits, Queenstown and Christchurch, New Zealand: The 2nd International Symposium on Transportation Network Reliability, pp. 80–186.

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Road Safety Advertisements Targeting Drunk Driving: Do Threat Appeals Actually Arouse Fear?

R. Markšaitytė[1], D. Šakinytė[2], L. Šeibokaitė[3], A. Endriulaitienė[4], K. Žardeckaitė-Matulaitienė[5], J. Slavinskienė[6]

[1]*Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: rasa.marksaityte@vdu.lt*
[2]*Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: dainora.sakinyte@stud.vdu.lt*
[3]*Vytautas Magnus University, Jonavos 66-330, Kaunas, Lithuania, E-mail: laura.seibokaite@vdu.lt*
[4]*Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: aukse.endriulaitiene@vdu.lt*
[5]*Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: kristina.zardeckaite-matulaitiene@vdu.lt*
[6]*Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: justina.slavinskiene@vdu.lt*

Abstract

Fear-arousing threat appeals are widely used in social marketing even though the research results on the effectiveness of threat appeals in road safety advertisements are controversial. However, only few studies examine whether threat appeals actually arouse fear and how this process influences the expected behaviour change. Thus, this study aims is to evaluate, whether road safety threat appeal advertisements targeting drunk driving arouse fear. 41 students (17.1 percent males; mean age 20.9 years) participated in the experimental study. Two road safety threat appeal advertisements targeting drunk driving and a clip of car wash advertisement were used as stimuli in the experiment. After watching the TV ad all participants had to evaluate the level of fear they felt. Study results revealed that both road safety threat appeal advertisements targeting drunk driving did not arouse fear (at least not stronger compared to usual advertisement). Even though both our road safety advertisements met the basic criteria for effective threat appeals, their effectiveness for drunk driving is still questionable. Further studies on the acceptance of road safety fear-arousing threat appeal advertisements are needed.

KEY WORDS: *road safety advertisement; drunk driving; fear-arousing threat appeal; fear*

1. Introduction

Social marketing is widely used by various public institutions and organizations to influence people's behaviour. Usually social marketing campaigns target different health behaviours (such like smoking, drug and alcohol use or diseases prevention, healthy eating, etc.), environment protection and ecological behaviour, physical activity, and road safety [9]. All these campaigns for the most part use fear-arousing threat appeals as a popular and effective tool to accept, modify, or reject our beliefs and behaviour [1-5, 9, 11-13, 22]. And the belief that the stronger the fear is, the more effective is the message, is often regarded as a truth of common sense in the field of social marketing [4, 5].

Drunk driving is one of the major road safety and public health concerns in the 21st century all over the world [13, 20]: up to 40 percent of road deaths are related to drunk driving [21]. Drunk drivers are at fault of every tenth road accident in Lithuania [23]. According to statistics, 18 people were killed and 324 were injured during these crashes in 2016 and during 2017 numbers decreased to 11 deaths and 297 injuries [10]. Even though the number of road accidents lately decreased, the drunk driving problem remains serious: only during two first weeks of year 2018 police caught 210 drunk drivers on Lithuanian roads [24].

Ditsuwan and colleagues state that road safety advertisements reduce drunk driving by 13 percent [8]. Social marketing with emotional appeals targeting drunk driving is considered more effective compared to rational persuasion and argumentations [9, 12, 17]. But the research results on the effectiveness of fear-arousing threat appeals in road safety advertisements are controversial. Of course, some previous research confirmed that threat appeals were effective in changing drunk driving attitudes, intentions, and behaviour [6, 9, 11]. Lennon and Rentfro found that the most significant predictor of advertisement effectiveness was the stronger level of fear aroused, especially for young drivers [11]. Other authors noted that threat appeals are not effective at all (even if a threat appeal arouse fear, it does not lead to any behaviour change) [4, 18], or even reported opposite results stating that threat and fear increase risky behaviour because of "boomerang effect" [5, 12, 22]. Still, the results of latest studies confirmed fear to be very important, but not the only explanatory factor of the effectiveness of road safety advertisement. For example, it is noticed that the most effective threat appeals are those which arouse medium strong fear [17]. Also, Carey and Sarma found that threat appeals were effective only together with higher self-efficacy of changing certain behaviour [4]. The demonstration of safer behaviours helping to avoid negative consequences of drunk driving at the end of road safety advertisement could also increase the effectiveness of threat appeal [1]. Other authors study different characteristics of the target audience for the effectiveness of threat appeals in road safety advertisements (gender, age, self-esteem, or personality) [11-13, 22]. While Algie and Rossiter focused their study on the process of fear arousal and change during the processing of road safety advertisement rather than on final feeling at the end of the message [1]. However, Lewis and colleagues argue that the first step in

measuring effectiveness of any road safety advertisement is to identify whether this message actually arouse fear. Threat appeals could evoke a range of negative emotions other than fear such as guilt, remorse, shame, disgust, or anger and because of that could be not effective at all [2, 13]. Unfortunately in Lithuania we do not have any scientific evidence on that even though threat appeals in social marketing is quite popular. Thus, this study aims is to evaluate, whether road safety threat appeal advertisements targeting drunk driving arouse fear.

Fear is an emotional response to any threatening stimuli or dangerous situation that could have any negative consequences to person and might motivate different behaviour in order to avoid these unwilling consequences [1, 4, 11, 15]. A typical road safety threat appeal advertisement targeting drunk driving presents negative physical (dead or injured body), social (loss of status or public condemnation), psychological (feelings of shame or guilt), or financial (loss of car or job) consequences [1, 19]. Based on previous research we know that presentation of obvious and realistic consequences of drunk driving, probability of the situation in real life of the audience, shocking images, scenes from actual car accidents, threatening verbal communication are key factors for fear arousal [1, 2, 4, 13 19, 20]. It is also known that images with dead or seriously injured bodies after drunk driving arouse the strongest fear while images of smashed car whit only verbal warning of possible death are not so effective in fear arousal [1, 7, 20]. Therefore we hypothesize that road safety threat appeal advertisements targeting drunk driving would arouse fear and that advertisement presenting a real death of pedestrian would arouse stronger fear compared to advertisement presenting just potential death threat. Based on the results that people could get used to the shocking messages in road safety advertisements [14, 20] and maybe are overwhelmed with threatening images and messages [12], we also assume that those, who see the specific road safety threat appeal advertisement targeting drunk driving for the first time, would report stronger fear.

2. Method

Participants. 41 students (7 males, 34 females) participated in the experimental study. All study participants were 19 – 25 years old (M = 20.9, SD = 1.7; no difference between males and females: Mann-Whitney U = 105.500, p = .632). 18 participants (19.5 percent) reported drunk driving at least once in their lifetime, and 23 participants (56.1 percent) indicated having experience of driving with drunk driver. Only 3 (7.3 percent) participants had experienced car crash, but none of it was related to drunk driving.

Research procedure and instruments. Ethical approval for the study was obtained from the Ethics Committee of Psychology at the Department of Psychology at Vytautas Magnus University. All students signed the informed consent to participate in the experiment and then were randomly assigned to one of three groups: two experimental and one control. The first experimental group watched road safety TV ad “Don’t drive after drinking – don’t become a killer” (expected level of aroused fear: strong), the second experimental group watch a TV ad “When driving after drinking, death breathes in your back” (expected level of aroused fear: medium) (see Table 1). Both TV road safety advertisements were obtained from the Lithuanian Road Administration. Control group participants saw a clip from car wash advertisement with no threatening stimuli.

Table 1

Description of advertisements

TV advertisement	Description of the content	Length
1st experimental “Don’t drive after drinking – don’t become a killer”	Shows a boy being hit by drunk driver on the pedestrian crossing followed by written and spoken words “LIFE IS NOT A FILM – YOU CANNOT ROTATE IT BACK”. The second scenario shows the same situation with the same sober driver stopping at the crossing to let the boy cross the street. The ad ends with phrase “DO NOT DRIVE AFTER DRINKING”.	30 secs
2nd experimental “When driving after drinking, death breathes in your back”	Shows two drunk young men starting to drive with loud music in the car. The voice behind the scene tell the viewer that “Alcohol is stronger then you. It humiliates and takes away your mind”. Suddenly the drunk driver barely controls the car and a man with hidden face (allusion to Death) appears on the back seat. The ad ends with phrase “WHEN DRIVING AFTER DRINKING, DEATH BREATHES IN YOUR BACK”.	25 secs
Control	Shows a girl driving blue car in front of different buildings. There is no music or other sounds than wind. The word “CARWASH” appears only at the very beginning of the ad.	30 secs

After watching a TV ad all participants were asked to evaluate 4 fear emotions on the scale from 1 to 7: how strongly are you afraid, tense, nervous, and scared. Later the sum of all emotions was calculated also (Cronbach alpha .904). Higher scores represented stronger fear after TV ad watching.

3. Results and Discussion

The descriptive characteristics of aroused fear after watching TV ads are presented in Table 2. Contradictory to expectations, statistical analysis revealed no difference between fear after watching the first road safety threat appeal TV

advertisement “Don’t drive after drinking – don’t become a killer” compared to the fear in control group: Mann Whitney U_{afraid} = 77.00, p = .370; Mann Whitney U_{tense} = 81.50, p = .491; Mann Whitney $U_{nervous}$ = 87.50, p = .687; Mann Whitney U_{scared} = 59.00, p = .078; Mann Whitney $U_{totalfear}$ = 73.50, p = .302. The same results were obtained when comparing fear aroused by the other road safety advertisement “When driving after drinking, death breathes in your back” with the feelings after watching car wash advertisement: Mann Whitney U_{afraid} = 66.50, p = .518; Mann Whitney U_{tense} = 72.00, p = .741; Mann Whitney $U_{nervous}$ = 66.50, p = .525; Mann Whitney U_{scared} = 66.50, p = .505; Mann Whitney $U_{totalfear}$ = 73.00, p = .785. Further analysis revealed that both road safety threat appeal advertisements targeting drunk driving didn’t differ in aroused fear: Mann Whitney U_{afraid} = 102.00, p = .929; Mann Whitney U_{tense} = 97.00, p = .755; Mann Whitney $U_{nervous}$ = 80.00, p = .285; Mann Whitney U_{scared} = 85.00, p = .393; Mann Whitney $U_{totalfear}$ = 88.00, p = .482. Thus both first and second hypothesis were not confirmed.

Table 2

Descriptive characteristics of fear emotions in experimental and control groups

Emotion	**1st experimental group “Don’t drive after drinking – don’t become a killer” (N = 16)**		**2nd experimental group “When driving after drinking, death breathes in your back” (N = 13)**		**Control group (N = 12)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Afraid	3.31	1.5	3.31	1.9	2.83	2.0
Tense	4.12	1.5	3.92	2.1	3.67	1.9
Nervous	4.06	1.9	3.31	1.9	3.75	1.9
Scared	3.44	1.8	2.85	1.9	2.25	1.6
Total fear	14.94	5.5	13.38	7.4	12.5	6.5

When analysing the importance of familiarity with certain road safety threat appeal advertisement in the past no differences in fear were observed (see Table 3). The third hypothesis was also rejected.

Such results lead to the conclusion that Lithuanian road safety threat appeal advertisements targeting drunk driving (at least two specific TV ads) do not arouse fear and because of that their effectiveness on reducing drunk driving is questionable. According to Carey, road safety advertisements could have been not sufficiently threatening [3]. Both road safety messages had potential to arouse fear: the ad “Don’t drive after drinking – don’t become a killer” presented a killed pedestrian boy with the threat for a viewer to became the same killer when driving after drinking; and a possible death threat with the image of damaged car because of drunk driving was presented in the ad “When driving after drinking, death breathes in your back”. However, it seems that more shocking stimuli are needed for causing fear in this case [1, 3, 16, 22].

Table 3

The comparison of aroused fear according to familiarity with certain road safety threat appeal advertisement in the past

Emotion	**Saw the road safety ad for the first time during the experiment (N = 14)**			**Had seen the road safety ad earlier (N = 15)**			***U***	***p***
	Mean	**SD**	**Mean Rank**	**Mean**	**SD**	**Mean Rank**		
Afraid	3.60	1.80	16.37	3.00	1.47	13.54	85.50	.363
Tense	4.07	1.98	15.03	4.00	1.57	14.96	104.50	.982
Nervous	3.60	1.84	14.63	3.86	2.07	15.39	99.50	.807
Scared	3.07	1.98	14.53	3.29	1.82	15.50	98.00	.754
Total fear	14.33	7.08	14.97	14.14	5.80	15.04	104.50	.983

On the other hand, some authors noted that removal of the threatening image could already cause a slight relief and fear decreases. More obvious fear reduction would be generated by recommending safer behaviour in order to avoid negative consequences or by demonstrating the second scenario of the same situation happy end [1, 5]. Based on these findings it could be assumed that both road safety advertisements could actually arouse fear but this feeling was not strong enough to observe after the ad with self-report questionnaire. Thus, further research should focus on the change of fear during the process of watching an advertisement and employ more of different subjective and objective measures [1]. Also other emotions than fear should be measured in the same studies in order to get broader understanding of how do really road safety threat appeal advertisements targeting drunk driving work and are understood by the audience [2, 13].

4. Conclusions

Even though both our road safety advertisements targeting drunk driving met the basic criteria for effective threat appeals, the messages didn’t actually arouse fear. Possibly, either both messages did not present a serious threat to the viewers or the fear was not strong enough to be measured. Thus, further studies on the effectiveness of threat appeals are needed.

References

1. **Algie, J.; Rossiter, J.R.** 2010. Fear patterns: A new approach to designing road safety advertisements, Journal of Prevention and Intervention in the Community 38(4): 264-279.
2. **Brennan, L.; Binney, W.** 2010. Fear, guilt, and shame appeals in social marketing, Journal of business Research 63(2): 140-146.
3. **Carey, R.N.** 2014. The Impact of threat appeals on risky driving behaviours. Doctoral dissertation. Galway: National University of Ireland, 182 p.
4. **Carey, R.N.; Sarma, K.M.** 2016. Threat appeals in health communication: Messages that elicit fear and enhance perceived efficacy positively impact on young male drivers, BMC Public Health 16(1): 645.
5. **Carey, R.N.; McDermott, D.T.; Sarma, K.M.** 2013. The impact of threat appeals on fear arousal and driver behavior: A meta-analysis of experimental research 1990 – 2011. PloS one 8(5): e62821.
6. **Cauberghe, V.; De Pelsmacker, P.; Janssens, W.; Dens, N.** 2009. Fear, threat and efficacy in threat appeals: Message involvement as a key mediator to message acceptance, Accident Analysis & Prevention 41(2): 276-285.
7. **De Pelsmacker, P.; Cauberghe, V.; Dens, N.** 2011. Fear appeal effectiveness for familiar and unfamiliar issues, Journal of Social Marketing 1(3): 171-191.
8. **Ditsuwan, V.; Veerman, J.L.; Bertram, M.; Vos, T.** 2013. Cost-effectiveness of interventions for reducing road traffic injuries related to driving under the influence of alcohol, Value in Health 16(1): 23-30.
9. **Helmig, B.; Thaler, J.** 2010. On the effectiveness of social marketing – What do we really know? Journal of Nonprofit and Public Sector Marketing 22(4): 264-287.
10. **Janstrup, K.H.** 2017. Road Safety Annual Report 2017. Technical University of Denmark, 581 p.
11. **Lennon, R.; Rentfro, R.** 2010. Are young adults fear appeal effectiveness ratings explained by fear arousal, perceived threat and perceived efficacy? Innovative Marketing 6(1): 58-65.
12. **Lennon, R.; Rentfro, R.; O'Leary, B.** 2010. Social marketing and distracted driving behaviors among young adults: The effectiveness of fear appeals, Academy of Marketing Studies Journal 14(2): 95-113.
13. **Lewis, I.; Watson, B.; Tay, R.; White, K.M.** 2007. The role of fear appeals in improving driver safety: A review of the effectiveness of fear-arousing (threat) appeals in road safety advertising, International Journal of Behavioral Consultation and Therapy 3(2): 203-222.
14. **Nabi, R.L.; Roskos-Ewoldsen, D.; Dillman Carpentier; F.** 2008. Subjective knowledge and fear appeal effectiveness: Implications for message design, Health Communication 23(2): 191-201.
15. **Peng, Y.** 2015. Interaction of Fear and Humor on Self-efficacy. The master thesis. Minneapolis: University of Minessota, 96 p.
16. **Peters, G.J.Y.; Ruiter, R.A.; Kok, G.** 2013. Threatening communication: A critical re-analysis and a revised meta-analytic test of fear appeal theory, Health Psychology Review 7(1): 8-31.
17. **Rhodes, N.** 2017. Fear - appeal messages: Message processing and affective attitudes. Communication Research 44(7): 952-975.
18. **Sibley, C.G.; Harre, N.** 2009. The impact of different styles of traffic safety advertisement on young drivers' explicit and implicit self-enhancement biases. Transportation Research Part F: Traffic Psychology and Behaviour 12(2): 159-167.
19. **Skorupa, P.** 2014. Shocking contents in social and commercial advertising, Creativity Studies 7(2): 69-81.
20. **Sweeney, K.** 2012. A study of the Road Safety Authorities use of fear appeals to communicate a public health message. Letterkenny Institute of Technology, 81 p.
21. **Wali, B.; Ahmed, A.; Iqbal, S.; Hussain, A.** 2017. Effectiveness of enforcement levels of speed limit and drink driving laws and associated factors – Exploratory empirical analysis using a bivariate ordered probit model, Journal of Traffic and Transportation Engineering (English edition) 4(3): 272-279.
22. **Zhang, X.** 2014. The influence of fear and authority on psychological reactance: A study of the effectiveness of public service announcement campaigns on drunk driving prevention among college students. Doctoral dissertation. Iowa: Iowa State University, 62 p.
23. Lietuvoje mažėja neblaivių asmenų sukeltų eismo įvykių, girtaujančių šeimų (in Lithuanian) [online cit: 2018 05 30]. Available from: https://www.ve.lt/naujienos/kriminalai/lietuvoje-mazeja-neblaiviu-asmenu-sukeltu-eismo-ivykiu-girtaujanciu-seimu-1638857/
24. **Steniulienė, I.** Šiemet nustatyta 210 neblaivių vairuotojų, pusė sulauks baudžiamosios atsakomybės (in Lithuanian) [online cit: 2018 01 15]. Available from: http://www.diena.lt/naujienos/kriminalai/nusikaltimai/siemet-nustatyta-210-neblaiviu-vairuotoju-puse-sulauks-baudziamosios-atsakomybes-846373

Proceedings of 22nd International Scientific Conference. Transport Means 2018.

The Issue of Live Animal Transport in the European Community on the Selected Example - Transport of Horses

M. Wincewicz-Bosy[1], J. Ryczyński[2]

[1]*General Tadeusz Kościuszko Military University of Land Forces (MULF), Czajkowskiego Street 109, 51-147 Wrocław, Poland, E-mail: marta.wincewicz-bosy@awl.edu.pl*
[2]*General Tadeusz Kościuszko Military University of Land Forces (MULF), Czajkowskiego Street 109, 51-147 Wrocław, Poland, E-mail: jacek.ryczynski@awl.edu.pl*

Abstract

Horse competition means horse racing, obstacle jumping, eventing, dressage, driving, and shows and comparisons within particular groups (e.g. ponies, horses). Pursuant to Article 44 of the Act on the organization of breeding and reproduction of livestock, "horse competitions serve to assess the value in use of equidae and are carried out in accordance with the European Community regulations on conducting horse competitions involving equidae". They play an important role in the implementation of breeding programs aimed at preserving biodiversity and improving individual breeds of horses. Their organization and obtained results are therefore not only an element of sports and entertainment, but they also translate into the value and prospects of breeding individual breeds. Organization of competitions in which teams from different countries participate is connected with the necessity to carry out movements: people, animals and physical goods. This is particularly important when organizing international competitions as World Cup finals or World Championships in individual equestrian disciplines. Due to the specificity of this sport, where the player is really a man and a horse team, the special importance of horse transport, which must reach the competition at the right time and condition.
The aim of the article is to present formal and legal conditions applicable in the EU, related to the movement of horses in order to participate in sport competition.
KEY WORDS: *transport of animals, equidae, European Community law regulations*

1. Formal and Legal Conditions of the International Movement of Equines

International transport of animals is an extremely complicated business area. On the one hand, it must be carried out efficiently and effectively enough to ensure the continuity and proper functioning of a large number of entities for which it is dedicated, which are intermediate links of food supply chains or other forms of food processing. On the other hand, its implementation should be in line with social expectations regarding the creation of appropriate conditions for its implementation, which will not have a negative impact on the animals being moved. On the third hand, its implementation must ensure the possibility of implementing the quality standard specified by the owners with respect to the condition, value and other features of the transported individuals. Due to the importance of animal transport processes, numerous regulations have been created whose primary task is to ensure the safety of their implementation in the socio-economic system. For the European area, and in particular entities belonging to the European Union, particular importance are [1-11]:

- European Convention for the Protection of Animals during International Transport;
- Animal health law;
- Council Regulation (EC) No 1/2005 on the protection of animals during transport and related actions amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No. 1255/97;
- Commission Regulation (EC) No 599/2004 concerning the adoption of a harmonized model certificate and inspection report related to the intra-Community trade in animals and products of animal origin;
- Commission Regulation (EC) No. 282/2004 introducing a document of registration and veterinary checks on animals imported into the Community originating from third countries and Commission Regulation (EC) No 585/2004 amending Regulations (EC) No 282/2004 introducing a document of registration and veterinary checks on animals imported into the Community originating in third countries;
- Commission Decision amending Decision 2004/292/EC on the introduction of the Traces system and amending Decision 92/486/EEC and Commission Decision 2009/821/EC establishing the list of approved border inspection posts, laying down certain rules for controls by veterinary experts of the Commission and establishing units veterinary in the TRACES system;
- Council Directive 91/496 / EEC laying down the principles governing the organization of veterinary checks on animals entering the Community from third countries and amending Directives 89/662 / EEC, 90/425 / EEC and 90/675 / EEC.

The above legal acts establish general principles related to the implementation of transport processes within the EU area, as well as with regard to procedures for importing, exporting and reimporting and exporting live animals. They primarily create a framework for economic activities in the field of animal transport, as well as for control procedures

that create elements of the security system of EU countries. They regulate in detail the scope of activity, documentation and technical requirements in relation to entities carrying out transport of animals for business purposes. They introduce general requirements for means of transport and loading areas used for moving animals, both for long-term journeys and those carried out up to 8 hours [14, 15, 18]. These regulations are given a special role by competent veterinarians in the sphere of identification of animals, recognition of their condition, as well as in the area of control of these processes - admission as healthy individuals to transport processes. They are also responsible for the procedures related to the issuing of relevant documents related to the permit to carry out commercial activities related to the transport of live animals in relation to persons and means of transport, and the implementation of control procedures.

The subject of special regulations are equidae. Due to the diversity of their functional destinies, and as a consequence of the specific attitude of many societies to these animals, they have separate regulations. The consequence of this situation is the creation of a separate regulation system for horses also with regard to the procedures of their movement. Due to the non-commercial nature of shipments related to participation in sports competitions, it is necessary to verify, in accordance with the will of the legislators, the applicable general regulations, so that they are adequate to the conditions organizing sport competition systems.

Regardless of the purposes for which the transport of animals is carried out, the basic conditions to which, in accordance with Article 3 of Regulation 1/2005/EC, belong [12, 18, 19]:

- take all necessary steps earlier in order to shorten the duration of transport to a minimum and ensure the needs of animals during transport;
- checking and stating that animals intended for transport processes are able to travel;
- ensuring that means of transport and loading and unloading equipment are designed, constructed, maintained and operated and act in such a way as to prevent injury and suffering, and in a manner that ensures animal safety;
- confirmation that the personnel dealing with animals have the appropriate training or competences required in this case and perform their duties without violence or any method causing unnecessary fear, injury or suffering;
- ensuring that transport is carried out without delay to the destination, while animal welfare is regularly monitored and maintained at an appropriate level;
- guaranteeing that the animals have adequate floor area and height, appropriate to their size and specificity as well as the time of the planned transport;
- confirmation that water, feed and rest are provided at appropriate intervals and correspond to the quantity and quality of the species and size of animals concerned.

The general rule adopted for transport processes is that no-one can transport animals or order animals to be transported in a way that causes them to be mutilated or causes them suffering.

2. Transport of Horses Taking Part in International Competitions in the EU

The basic element indispensable for the implementation of all horse movements is their proper identification. Irrespective of the nature and purpose of the journey, the owner of an equine animal who may or may not be the owner is responsible for the identification of equidae in accordance with Regulation 2015/262/EU on the basis of Council Directives 90/42/EEC and 2009/156/EC, rules on methods for identifying equidae (regulation on horse passport). A holder within the meaning of the above Regulation is a natural or legal person who owns an equine animal or is entrusted with the care of such an animal, for financial consideration or free of charge, permanently or temporarily, also during transport, at trade fairs or during competitions , races or cultural events. Identification of equidae includes [22]:

- establishment of one lifetime identification document containing: a description of the animal, a completed graphic description and a place for identification entries, consistent with the formula constituting the relevant Annex I to Regulation 2015/262/EU;
- providing an unambiguous method of verifying the identity and unambiguous linking of the identification document with the animal - currently a transponder is used, implanted between the occipital and withers, issued by the competent institution at the time of the first identification, with the data entered into the identification document;
- database and central database with registered data of the identified animal.

ID (passport) also contains information on health conditions, laboratory tests, vaccinations and administered medicinal products. This information is an important element of the phyto-sanitary and epidemiological system of areas where individual individuals reside. In addition to the derogations mentioned in Article 23 of Regulation 2015/262/EU, identification documents should permanently accompany equidae in movements and transport or under Article 25, when it concerns the territory of the home country, they should have an electronic card in accordance with the model in Annexes II to the above Regulation.

The basic rules for the movement of equidae between EU Member States are regulated by Chapter II, Council Directive 2009/156 / EC on health conditions regulating the movement and import of equidae from third countries. According to its provisions, Member States shall approve the movement of registered equidae into their territory or send equidae to another Member State only if they fulfill the relevant conditions. Among them is the requirement of origin from farms free from infectious diseases and prohibitions identified in Article 4 paragraph 5, as well as the lack of contact with other equines suffering from an infectious or contagious disease, 15 days before the examination confirming the proper health of the horse, confirmed by appropriate document: a health certificate or a health certificate. This document shall be drawn up 48 days before loading, no later than on the last working day preceding loading. Registered equidae

must be equipped with appropriate identification documents. The basic principle of the carried out movements is that horses should be transported as soon as possible from the farm / place of origin to their destination, in vehicles or containers that have been regularly cleaned and disinfected. Transport must be organized in such a way as to effectively protect the health and welfare of equidae.

3. Organizational Determinants of International Equestrian Events Associated with the Transport of Horses

Horse transport associated with equestrian events is subject to numerous formal and legal regulations. Unfortunately, today there are no uniform rules dedicated to this area of transport. Therefore, it is necessary to refer to legal acts regarding the movement of animals and the movement of equidae. The basic problem of existing regulations is that they regulate the movement of animals in the economic system and for commercial purposes. Whereas riding competitions do not bear the characteristics of trade, which, in a sense, take into account the legislators introducing reservations regarding the exclusion of partial transport of this type from the applicable regulations. At the same time, in many legal acts a reservation is made that in the situation of transporting horses related to competitions (contests) one should refer, for the benefit of animals, to the already mentioned provisions. This causes numerous difficulties of formal and legal nature, especially in the situation of control carried out by the authorities of individual states and EU institutions.

The system of equestrian competitions extends beyond the preparation of appropriate infrastructure, ensuring proper information-and-decision flows, physical flows (people and animals and materials) and financial flows [17]. According to the regulations in force, the organizer of the competition is obliged to notify the appropriate institutions and obtain their positive recommendations resulting from the fact that the competition is classified as a mass event (police and security services, commune office - as an appropriate administrative unit, medical and veterinary services, sanitary, e.g.). The basic duties also include drawing up appropriate "proposals for the competition" in accordance with the FEI regulations [1, 15]. It is a document containing all information about the place of the competition and technical conditions, organizers, the referee team, programs of individual competitions, costs and prizes.

Regardless of the rank of the competition and the place where they are played, an important element related not only to the disposition of the competitor, but above all to the mind and condition of the horses, is the transport process. The choice of means of transport, travel time and adaptation to the psycho-physical conditions of horses is of particular importance for the results obtained. Transport in the context of equestrian events concerns mainly bringing horses to the place where the competition takes place and leaving the site where they took place. The organizers of the competition are obliged to provide in the "proposals for the competition" the exact date of commencement and completion of sports competitions, as well as dates of submission to the applicable procedures, and lists of points of crossing borders in which veterinary clearance can be performed. This document also contains the specification of valid veterinary standards (documents and procedures) in the country and at the place where the competition takes place. It also provides information on the possible, maximum possible date of arrival of horses for competition and the date of the eventual departure from the competition area.

In planning and implementing the processes of moving horses in connection with international competitions, the office of the competition plays a special role. It is a unit appointed by the organizer, in accordance with the requirements of FEI, to coordinate information flows, documents, service: judges and other official persons, players and horses. The competition office also helps in the implementation of procedures related to international transport and the necessary documentation for its implementation. Therefore, in "proposals for professions", border checkpoints are exchanged with which the competition organizers maintain constant contact and, if necessary, offer assistance in documentary and veterinary procedures. Competitors, when they arrive at the venue and report to the competition office, receive a complete set of up-to-date information and carry out all documentation procedures.

An important organizational element, for safety reasons, is also the provision of an appropriate means of transport in the event of an accident or sudden illness of the animal, allowing it to be transported to the appropriate veterinary clinic. In this case, the legislator waives the requirements for regulating the transport of animals. However, in such a situation, the organizers are obliged to comply with the FEI regulations. Among them is the obligation to prepare a specialized means of transport, available to the competition organizer 24 hours a day, throughout the duration of the project, i.e. from the arrival of the first horses, until the last of them, from the competition area. Most often it is a special truck or a set of a car and a special trailer that have the right equipment. It is also necessary to provide a qualified driver, possessing not only relevant documents and road authorizations, but also the skills and experience in handling: loading, unloading and transporting horses in emergencies. Animals for emergency transport require special treatment, which is why it is necessary to organize a team of people who will be able to participate in this process upon request. Among these people with specific qualifications and skills, there should also be a veterinarian who will look after the animal during the transport process and all activities connected with it.

The organizer of international equestrian competitions is responsible for the preparation and conduct of all control processes and the preparation of appropriate documentation, as well as for the performance of activities related to the implementation of horse transports related to this competition. It is also the responsibility of the organizer to ensure that all the procedures necessary to leave the competition site by the animals are taken, both in order to go to their place of permanent residence, as well as the further implementation of the journey resulting from the plan to participate in subsequent competitions under the FEI system.

To maintain an appropriate level of process optimization, proper layout of the horse movement system is of particular importance. It should be remembered that the transport of animals is a stressful factor. This is important for the

psychological and physical condition of the animal. Each trip is an element that negatively affects the horses, which translates into the results obtained during take-offs. Physical damage may be the reason for exclusion from participation in the competition. Therefore, technical conditions related to transport should be included in the planning. This applies not only to the technical condition of the means of transport, but also to the skills and knowledge of the carrier and staff, as well as proper planning of the route and travel times together with appropriately selected milestones (control). In the case of participation in the international competition system, control procedures, including border / customs and veterinary procedures, should also be taken into account.

Movement planning should take into account both horses, players and support teams of the so-called team. Most often the team consists of grooms, trainers, veterinarians and drivers. The size and composition of the team depends on the financial possibilities and the number of horses on which the competitor starts. When planning the start-up season, it is necessary to properly plan and organize places of stay and routes of trips. It should also take into account the time needed to implement the admission procedures, as well as the time necessary for acclimatization of the horse. An essential element is the integration with the processes of movement, feed flow (in a timely manner, quantity and quality) delivered to the places of planned stay. An important element of the movement is also riding equipment and training, which accompanies riders and horses. In the season of starts, competitors and horses stay outside the home area for several or even several weeks.

4. Summary

Moving live animals is an extremely complicated element of the economic system, affecting various aspects of the functioning of people, institutions, enterprises, states and integration groups. The development of the horse business, which is related, among other things, to the growing popularity of equestrian undertakings, and especially to horse competitions, makes the non-commercial movements of horses more important in this system. Therefore, for the further development of this area, it is necessary to properly recognize its condition, especially the conditions of the organizers. Lack of separate regulations, while allowing discretion in the application of general norms, causes numerous complications and leads to stressful situations. It also lowers the possibilities of efficient development.

Global conditions created to standardize equestrian disputes affect the need to create adequate solutions on the national and community level. Particular attention should be paid to the creation of standards that are unambiguous and easy to identify and apply by individual citizens. Especially considering their advancement in the areas of zootechnical or sports knowledge, not law. The considerations presented in the article are an attempt to indicate the existing solutions and standards in the horse transport system between EU member states in connection with the participation in international equestrian competitions, as well as identification of standards and procedures related to the movement of horses in equestrian competitions.

References

1. Annual Report 2012, 2013, 2014, 2015, FEI, Lausanne, Switzerland; FEI Calendary 2016.
2. **Chrzan, T.; Smal, T.** Road Safety Audit in Poland. Proceedings of 20th International Scientific Conference - Transport Means 2016. Part I. October 5-7, 2016, Juodkrante, Lithuania. p. 102-106. ISSN 1822-296 X (print), ISSN 2351-7034 (on-line).
3. Commission Decision No. 2005/231/EC amending Decision 2004/292/EC regarding the introduction of the Traces system and amending Decision 92/486 / EEC U. L 39, 11.02.2005, p.53.
4. Commission Decision No. 2009/821/EC establishing the list of approved border inspection posts, establishing some principles of controls carried out by veterinary experts of the Commission and establishing veterinary units in the TRACES system. U. L 296, November 12, 2009, p. 1.
5. Council Directive No. 2009/156/EC on health conditions regulating the movement and import of equidae from third countries U. L 192 of 23.07.2010.
6. Council Directive 90/428/EEC on trade in equidae intended for competition and laying down the conditions for participation in such professions. U. L224 of August 18, 1990, p. 60 with amendments.
7. Council Directive 91/496/EEC laying down the principles governing the organization of veterinary checks on animals entering the Community from third countries and amending Directives 89/662 / EEC, 90/425/EEC and 90/675/EEC U. L 268, 24/09/1991, p.56.
8. Council Regulation (EC) No 1/2005 on the protection of animals during transport and related actions amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No. 1255/97. U. L 3, 5.01.2005.
9. Council Regulation 1255/97/EC concerning Community criteria for control posts and amending the route plan specified in the Annex to Directive 91/628 / EEC. U. L 174, 2 July 1997, p. 1 with later d.
10. Commission Regulation (EU) 2015/262 specifying, on the basis of Council Directives 90/427 / EEC and 2009/156/EC, rules on the methods of identification of equidae (regulation on the horse's passport) U. L59 from 03/03/2015.
11. Commission Regulation (EC) No. 282/2004 introducing the document of registration and veterinary control of animals imported into the community originating from third countries Dz. U. L 49, 19.02.2004, p.11.
12. Commission Regulation (EC) No. 585/2004 amending Regulations (EC) No. 282/2004 introducing a document of registration and veterinary control of animals imported into the Community originating from third countries Dz. U. L 91 of 30/03/2004, p. 17.

13. Commission Regulation (EC) No 599/2004 concerning the adoption of a harmonized model certificate and inspection report related to the intra-Community trade in animals and products of animal origin. U. L 94, 31.03.2004, p. 44.
14. European Convention for the Protection of Animals during International Transport. Journal U. L 241 of 13.07.2004.
15. General Regulations 23rd edition, 1 January 2009, updates effective1 January 2016, FEI, Switzerland, Lausanne.
16. Instruction of the Chief Veterinary Officer No. GIWz.420 / AW-62/11 from 2011 on the proceedings of poviat veterinary surgeons in: approving carriers and means of road transport used for transporting animals, vehicle inspections, carrying out control of the performance of road transport of animals in terms of their well-being and reporting on the controls carried out in this area.
17. **Kopczewski, M.; Smal, T.** 2016. Transportation of Dangerous Goods – Legal and Technical Conditions and Marking of Vehicles. Proceedings of 20th International Scientific Conference - Transport Means 2016. Part I. October 5-7, 2016, Juodkrante, Lithuania. p. 191-196. ISSN 1822-296 X (print), ISSN 2351-7034 (on-line).
18. Regulation of the Polish Minister of Agriculture and Rural Development of 26 April 2004 on detailed veterinary requirements for conducting activities in the field of commercial transport of animals or transporting animals carried out in connection with the conduct of other economic activities Dz. U. of 2004 No. 100 item 1012 of 25/04/2004.
19. Regulation (EU) No 2016/1012 of the European Parliament and of the Council of 8 June 2016 on zootechnical and genealogical conditions for the breeding and trade of pure-bred breeding animals and hybrids of pigs, entering them into the Union territory and trading them with biological material used for reproduction and its introduction into the Union territory and amending Regulation (EU) No 652/2014, Council Directives 89/608 / EEC and 90/425 / EEC and repealing certain acts in the field of animal husbandry ("Regulation on animal husbandry") . U. L 171 of 29.06.2016 p.66.
20. Regulation 2016/429 of the European Parliament and of the Council on transmissible animal diseases and amending repealing certain acts in the field of animal health U. L 84, 31.03.20016.
21. **Ryczynski, J.** 2016. The Example Of Modeling Of Logistics Processes Using Differential Equations, Proceedings Of The International Conference On Numerical Analysis And Applied Mathematics 2016 (ICNAAM-2016), Book Series: AIP Conference Proceedings, Volume: 1863, Article Number: UNSP 230008, Published: 2017.
22. **Wincewicz-Bosy, M.** 2012. Networks of business entities in horse business (orginal in Polish), Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu, Wrocław 2012.

Author's Index

Contents

Proceedings of 22nd International Scientific Conference Transport Means
ISSN 1822-296 X (print)
ISSN 2351- 7034 (online)

Design by Rasa Džiaugienė, Rolandas Makaras, Robertas Keršys, Saulė Kvietkaitė

Cover Design by Publishing House „Technologija“

Printer‘s sheets Order No. Price on request.
Publishing House „Technologija“ , Studentų st. 54, 51424, Kaunas