TRANSPORT MEANS 2020
Sustainability: Research and Solutions

PROCEEDINGS OF THE 24th INTERNATIONAL SCIENTIFIC CONFERENCE

PART II

September 30 - October 02, 2020
Online Conference - Kaunas, Lithuania
CONFERENCE IS ORGANIZED BY
Kaunas University of Technology,
In cooperation with
Klaipeda University,
IFToMM National Committee of Lithuania,
Lithuanian Society of Automotive Engineers,
The Division of Technical Sciences of Lithuanian Academy of Sciences,
Vilnius Gediminas Technical University


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.

All rights preserved. No part of these publications may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the permission of the publisher.

© Kaunas University of Technology, 2020
SCIENTIFIC EDITORIAL COMMITTEE

Chairman – Prof. V. Ostaševičius, Member of Lithuanian and Swedish Royal Engineering Academies of Sciences, Chairman of IFToMM National Committee of Lithuania

MEMBERS

Prof. H. Adeli, The Ohio State University (USA)
Dr. A. Alop, Estonian Maritime Academy of Tallinn University of Technology (Estonia)
Dr. S. Backaitis, US Transportation Department (USA)
Prof. Z. Bazaras, Department of Transport Engineering, KTU (Lithuania)
Prof. M. Bogdevičius, Faculty of Transport Engineering, VGTU (Lithuania)
Dr. D. Bazaras, Faculty of Transport Engineering, VGTU (Lithuania)
Prof. R. Burdzik, Silesian University of Technology (Poland)
Prof. P.M.S.T. de Castro, Porto University (Portugal)
Prof. R. Cipollone, L’Aquila University (Italy)
Prof. Z. Dvorsk, University of Žilina (Slovakia)
Prof. A. Fedaravičius, Department of Transport Engineering, KTU (Lithuania)
Dr. S. Himmetoglu, Hacettepe University (Turkey)
Dr. hab. J. Jacyna-Golda, Warsaw University of Technology (Poland)
Dr. J. Jankowski, Polish Ships Register (Poland)
Prof. I. Kabashkin, Transport and Telecommunications Institute (Latvia)
Prof. A. Keršys, Department of Transport Engineering, KTU (Lithuania)
Dr. B. Leitner, University of Žilina (Slovakia)
Dr. J. Ludvigsen, Transport Economy Institute (Norway)
Prof. V. Lukoševičius, Department of Transport Engineering, KTU (Lithuania)
Prof. M. Lukoševičius, Department of Transport Engineering, KTU (Lithuania)
Prof. J. Majercak, University of Žilina (Slovakia)
Dr. R. Makaras, Department of Transport Engineering, KTU (Lithuania)
Dr. R. Markšaitė, Vytautas Magnus University (Lithuania)
Prof. A. Mohany, Ontario Tech University (Canada)
Prof. V. Paulauskas, Department of Marine Engineering, KU (Lithuania)
Prof. O. Prentkovskis, Faculty of Transport Engineering, VGTU (Lithuania)
Prof. V. Friednieks, Latvian Maritime Academy (Latvia)
Dr. L. Raslavičius, Department of Transport Engineering, KTU (Lithuania)
Dr. J. Ryczynski, Tadeusz Kosciusko Military Academy of Land Forces (Poland)
Dr. D. Rohacs, Budapest University of Technology and Economics (Hungary)
Prof. M. Sitarcz, WSB University, (Poland)
Prof. D. Szpica, Bialystok University of Technology (Poland)
Dr. C. Steenberg, FORCE Technology (Denmark)
Dr. A. Šašaš, Faculty of Transport Engineering, VGTU (Lithuania)
Dr. Ch. Tatkeu, French National Institute for Transport and Safety Research (France)
Prof. M. Wasik, Warsaw University of Technology (Poland)
Prof. Z. Vınt, University of Defence (Czech Republic)

ORGANIZING COMMITTEE

Chairman – Prof. Ž. Bazaras, Department of Transport Engineering, KTU (Lithuania)
Vice-Chairman – Prof. V. Paulauskas, Department of Marine engineering, KU (Lithuania)
Vice-Chairman – Prof. A. Fedaravičius, Department of Transport Engineering, KTU (Lithuania)
Secretary – Dr. R. Keršys, Department of Transport Engineering, KTU (Lithuania)

MEMBERS

Dr. R. Junevičius, Vice-Dean for Research of the Faculty of Transport Engineering, VGTU
Dr. A. Vilkauskas, Dean of the Faculty of Mechanical Engineering and Design, KTU
Dr. R. Makaras, Head of Department of Transport Engineering, KTU
Dr. V. Dzerkelis, Department of Transport Engineering, KTU
Dr. B. Płaćienė, Department of Marine engineering, KU
Dr. A. Keršys, Department of Transport Engineering, KTU
Dr. S. Japertas, Department of Transport Engineering, KTU
Dr. R. Skvireckas, Department of Transport Engineering, KTU
Dr. A. Pakalnis, Department of Transport Engineering, KTU
Dr. S. Kilikevičius, Department of Transport Engineering, KTU
Dr. V. Lukoševičius, Department of Transport Engineering, KTU
Dr. D. Juodvalkis, Department of Transport Engineering, KTU
Dr. A. Pakalnis, Department of Transport Engineering, KTU
Dr. N. Keršienė, Faculty of Mechanical Engineering and Design, KTU
R. Džiaugienė, Department of Transport Engineering, KTU
M. Lendraitis, Department of Transport Engineering, KTU
R. Litvaitis, Department of Transport Engineering, KTU

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

24th international scientific conference TRANSPORT MEANS 2020 due to the COVID-19 pandemic in the world, for the first time was organized as a virtual event on 30 September - 02 October, 2020. 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 wide 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
Comparison of Overcoming Inequalities of the Road by a Vehicle with a Conventional Drive System and Electric Motors Placed in the Wheels

K. Parczewski¹, H. Wnęk²

¹University of Bielsko-Biała, Willowa 2, 43-309, Bielsko-Biała, Poland, E-mail: kparczewski@ath.bielsko.pl
²University of Bielsko-Biała, Willowa 2, 43-309, Bielsko-Biała, Poland, E-mail: hwnek@ath.bielsko.pl

Abstract

The article presents issues related to the driving comfort of a vehicle equipped with electric motors placed in the wheels. The paper presents the results of vehicle tests carried out while overcoming road unevenness of various shapes. Two typical inequalities were selected for the tests, corresponding to the case of passing through an unevenness or an object on the road and when driving into and out of a road hole. The tests were carried out using a B-class car. The analysis was based on the obtained measurement results. The difference resulting from the speed of driving through the obstacle and the shape of the obstacle is shown. The article allowed presenting the characteristics of changes in the amplitude of the body vibrations with the change of the driving speed. The energy lost for overcoming unevenness and the labor of driving through road unevenness for different vehicle speeds of motion is presented.

KEY WORDS: road surface unevenness, electric car, electric motors in wheels, driving comfort

1. Introduction

Vehicle modifications caused by the use of hybrid or electric drive systems cause the mass parameters of vehicles to change. In the case of a hybrid vehicle, this increases the weight of the vehicle by at least the weight of electric motors and their cooling and control systems. In an electrically driven car, the drive system developed in the classic system (engine, clutch, gearbox, main gear, driveshafts) can be reduced to motors mounted in wheel hubs [8]. This solution of the drive train, consisting in mounting electric motors in the wheels of the vehicle, has been analysed in detail due to its simplicity of construction, ease of controlling the drive and braking of the vehicle. Another advantage is the high reliability of this type of vehicle construction.

It can be problematic to place the motor and brake in the wheel disc due to their dimensions. Placing the electric motor in the wheel hub increases the mass that rotates with the wheel and the mass associated with the suspension. These modifications have a negative effect on the ratio of unsprung mass to sprung mass.

In cars powered by electric motors, despite the reduction in the number of driveline components, the weight of the vehicle usually does not decrease. The reason is the necessity to use batteries with a relatively large weight and cooling and control systems for electric motors.

Placing electric motors in the wheels of the vehicle increases the mass and moments of inertia of the wheels. This affects the dynamics of vehicle movement, steerability, safety and the driving comfort of users. Many authors have conducted research on these features of vehicles [1-4, 6, 11]. The requirements for motors mounted in wheel hubs are high, because with relatively small overall dimensions they must have a large torque necessary to start driving and accelerate the vehicle. There are also greater requirements for engine control while driving on road curves in changing traffic conditions [5, 7]. Increasing the unsprung masses will also affect the vehicle's behaviour during acceleration and braking, especially on surfaces with different coefficients of traction under the wheels of the right and left sides of the vehicle.

Fig. 1 View of the real road unevenness: a – potholes; b – breach in the road

The article presents the results of analyses of overcoming road unevenness of various shapes. Roads after the winter period, with intense traffic, deteriorate, which causes breakouts and unevenness of the road. In the case of minor damage or elements on the road, the vehicle overcomes them by driving over them, in the case of major damage to the road; the car's wheel enters and leaves the breach in the road. Examples of road unevenness are
shown in Fig. 1. The method of overcoming unevenness by the vehicle wheel, allowed distinguishing two types of unevenness of various shapes: triangular and rectangular, in the case of which the mechanics of overcoming the unevenness is different.

2. Overcoming Road Unevenness of Triangular and Rectangular Shape

Road unevenness of various shapes was selected for the investigation. The first of them - triangular road inequality, corresponds to the situation in which the vehicle overcomes the unevenness and continues to drive on the road. In the second case of driving over a rectangular unevenness, the vehicle enters on the road unevenness, drives through and leaves the unevenness. In the first case, the transient lift of the wheel axle results from the unevenness height, driving speed, wheel load and tire pressure. In the vast majority of cases, the lift of the wheel axle is lower than the height of the roughness. The ride through the triangular inequality was described by the authors in [9, 10] using for this purpose the Zegelar model [12-13].

If the vehicle overcomes by the rectangular shape unevenness and the length of the unevenness is significantly greater than its height, than the lift of the wheel axle will be close to the height of the unevenness, during driving on the unevenness and after stabilizing the vibrations. In this case, the lift of the wheel axle is usually greater than when negotiating triangular shape irregularities. The greater lift of the wheel axle increases the amplitude of the suspension vibrations and the speed of movement of the shock absorber piston rod. The differences in overcoming triangular and rectangular shape inequalities are shown in Fig. 2. The same height of both inequalities was assumed.

![Fig. 2 Vehicle wheel overcoming road unevenness of various shapes: a – triangular; b – rectangular](image)

By analysing these two cases, it is worth assessing the work performed by the suspension and the energy of movement of the shock absorber. For this purpose, the following relationships were used to evaluate labour and energy.

The suspension labour:

\[
W_s = \sum m_{bs} \cdot v_{zsi} \cdot v_{zsi}.
\]  

(1)

The energy lost in suspension:

\[
E_s = \frac{1}{2} \sum m_{bs} \cdot v_{zsi}^2.
\]  

(2)

where \(W_s\) - vehicle suspension work; \(v_{zsi}\) - shock absorber piston rod speed; \(v_{zsi}\) - vehicle speed; \(m_{bs}\) - mass occurs per wheel of the vehicle.

Due to the fact that tests were carried out at low driving speeds, the influence of inertia forces acting on the vehicle body was ignored.

In the period of increased interest in electric drive cars, the analysis was carried out for a vehicle with a classic drive system and for a vehicle with electric motors mounted in the wheels. Data of the SMzs200S32 engines produced by KOMEL [1], with a total power of ~ 80 kW and a maximum torque of 400Nm, intended for this class of vehicles, were used. The analysis was based on the test results of a class B car.

3. Vehicle Testing

Road tests of a class B vehicle (total mass = 1300 kg) were carried out, equipped with additional masses simulating the presence of two electric motors mounted in the wheels of the vehicle.

The tests were carried out in two mass configurations: a standard vehicle and a vehicle supplemented with additional masses simulating the presence of electric motors on the rear axle. Installing additional masses simulating the engines in the wheels increased the total weight of the vehicle by 70 kg. Additional masses simulating the mass of the engine rotor were attached to the rims of the rear wheels, thanks to which these masses rotated with the wheels and the masses of the non-rotating stators were attached to the suspension elements. Suspension spring stiffness and damping factors of shock absorbers are assumed to be the same for both drive configurations. Additional masses are shown in Fig. 3.
During the tests, were measured: the movement of the wheel axle and suspension deflection, acceleration (vertical and longitudinal) of the wheel axle, the acceleration of body above the wheel and in the centre of gravity of the vehicle, vehicle speed, rotational speeds on every wheels and angular velocities of centre of gravity measured in three directions: longitudinal, transverse and vertical. The measurements were performed with a frequency of 200 Hz and saved in the memory of the measuring device.

Fig. 4 Arrangement of sensors in the vehicle: 1 – wheel axis distance sensor from the road, wheel rotational speed sensor, acceleration sensor; 2 – body distance sensor from wheel axis, acceleration sensor; 3 – vehicle velocity sensor, acceleration sensor, gyroscopes; 4 – wheel rotational speed sensor

4. Measurement Results

Driving over a triangular unevenness

On the basis of the measurements, the wheel axle lift and the vertical movement of the car body (points 1 and 2 in Fig. 4) were determined while overcoming triangular inequalities. These values are shown in Fig. 5.

[Graph showing wheel axle lift and body vertical movement at different speeds]

When the electric motors were used in the wheels of the vehicle, the curves presented in the charts changed, as shown in Fig. 6.

Comparing the curves while overcoming triangular inequalities, it can be noticed that installing electric motors in the wheels of the vehicle will result in greater deflection of the tires, which will reduce the amplitude of vibrations of the wheel axles. This change will also reduce the amplitudes of the body vibrations over the wheels. Moreover, the assembly of motors will extend the time of damping the vibrations of the wheel axle.
Fig. 7 shows a comparison of vertical accelerations acting on the car body with and without wheel motors.

Comparing the acceleration curves of the rear part of the body when overcoming triangular inequalities, it can be seen that mounting the electric motors in the wheels of the vehicle has little effect on acceleration.

**Driving over a rectangular shape unevenness**

Similar measurements were carried out while overcoming rectangular unevenness. The wheel axle lift and the vertical movement of the body (points 1 and 2 in Fig. 4) are shown in Fig. 8.
When the electric motors were used in the wheels of the vehicle, the curves presented in the charts changed, as shown in Fig. 9.

Comparing the curves (Fig. 9) while overcoming rectangular unevenness, it can be noticed that the installation of electric motors in the wheels of the vehicle has little effect on the wheel axle vertical movement. There is a slight increase in amplitude at low speeds. The maximum amplitudes of the body vibrations will decrease more slowly. As in the case of triangular-shaped unevenness, the time of damping the vibrations of the wheel axle will be longer.

Fig. 10 shows a comparison of vertical accelerations acting on the car body with and without wheel motors.

Comparing the curves of the acceleration of the rear part of the car body while overcoming the unevenness of a rectangular shape (Fig. 10), it can be noticed that mounting electric motors in the wheels of the vehicle increases the acceleration amplitudes.

5. The Influence of Mounting Motors in Wheels on Overcoming Road Unevenness

The conducted research made it possible to compare the vehicle's behaviour while overcoming the unevenness of various shapes at different driving speeds.

Fig. 11 shows a comparison of the maximum amplitudes of vertical vibrations of the body, measured at point 2 of the vehicle with and without wheel motors while driving at different speeds. Increasing the driving speed reduces the amplitude of the body vibrations. When overcoming triangular-shaped bumps, mounting motors in the wheels of the vehicle results in a reduction in amplitude. The vehicle behaves in the opposite way when overcoming the unevenness of a rectangular shape. In this case, mounting the motors in the wheels increases the amplitude of vibrations.

The energy lost in the suspension and the operation of the vehicle while overcoming unevenness were also compared. Fig. 12 shows the energy losses when overcoming the unevenness of the vehicle without wheel motors and with the motors installed.

Mounting the motors in wheels significantly increases the energy lost in the suspension from 2.5 times in the case of a triangular obstacle to several times in the case of a rectangular obstacle.
Fig. 13 shows the labour of the car while overcoming unevenness at various speeds, without wheel motors and with the motors installed.

Mounting the motors in the wheels significantly increases the labour needed to overcome the obstacle. The greater labour value when overcoming a rectangular obstacle results from the greater vertical movement of the wheel.
6. Summary and Conclusions

The solution of the drive system of electric vehicles with motors mounted in the vehicle wheels is one of the most promising due to the significant simplification of the drive system. It has a number of advantages, but is associated with a reduction in driving comfort. One of the determinants of the assessment of comfort may be overcoming the unevenness of the road. When the car overcomes uneven roads, the axles of the car wheels move vertically in relation to the road and the body. The speed of this movement, the acceleration of the wheel and the body, are determined by the height and shape of the unevenness. The most typical cases were selected for the analysis: driving over unevenness or an obstacle lying on the road and driving into and out of a hole. The amplitudes of the vertical movement of the wheel and body axles, the acceleration of the wheel and body axles above the wheel, as well as vehicle work and energy lost in the suspension were analysed. The presented analyses allowed determining the characteristics of the change in the amplitude of the vertical movement of the body depending on the driving speed.

Vehicles with engines mounted in wheels show an increase in vibration amplitudes by several percent compared to vehicles without engines. The labour of the vehicle while overcoming unevenness increases several times. The energy lost in the suspension increases $2^3$ times when the motors are mounted in the wheels.

References

Treatment Methods of Ships Sewage: A Theoretical Analysis

R. Kalniņa¹, I. Ivaņinoka²

¹Latvian Maritime Academy, Flotes 12 k-1, Riga, Latvia, E-mail: rena.te_kalnina@inbox.lv
²Latvian Maritime Academy, Flotes 12 k-1, Riga, Latvia, E-mail: leva.ivaninoka@gmail.com

Abstract

Sewage causes significant changes in water quality, as it contains nitrogen and phosphorus. Ship's sewage water also contains bacteria, viruses, detergents, and heavy metals that irreversibly produce waterborne effects. This leads to eutrophication and other alterations, such as dead zones, algae breeding and fish population changes. This paper analyses regulations for the prevention of pollution from sewage as stricter requirements are set for passenger ships operating in the Baltic Sea. Ships can use sewage treatment systems. The secondary phase is very important, therefore biological treatment methods are analyzed.

KEY WORDS: Baltic Sea, biological treatment methods, eco effectiveness, ships sewage

1. Introduction

Pollution is a direct or indirect human activity where the entry of substances or energy in the marine environment can cause consequences - human health threats and damage to living resources, obstruct legitimate uses of the sea (fishing; recreational purposes) [1]. Environmental pollution is one of the biggest problems affecting almost all inhabited areas. The Baltic Sea is one of the most polluted seas, as a result of anthropogenic exposure and because of low salinity and water exchange with the North Sea. The Baltic Sea is particularly sensitive to eutrophication [2].

Ships sewage is the main source of phosphorus and nitrogen for the marine environment. The total annual nutrient content of toilet sewage from cruise ships can be roughly estimated at 86–107 tonnes of nitrogen and 30–36 tonnes of phosphorus, depending on the figures used for nutrient content of daily toilet sewage per person. Also, sewage is produced by 40 million passengers onboard international ferries as well as the uncalculated number of voyages by smaller ferries and leisure boats [3]. Improperly treated sewage on-board can harm the ecosystem. Most of the vessels have a sewage treatment system [4] that can be improved with new methods to treat nutrients.

2. International and National Regulations

The International Convention for the Prevention of Pollution from Ships, 1973, and as modified by the Protocol of 1978 relating thereto and by the Protocol of 1997 (MARPOL 73/78) aim is to prevent the deliberate pollution of the marine environment by oil and other harmful substances and to minimize the accidental release of such substances [5]. It is generally considered that on the high seas, the oceans are capable of assimilating and dealing with raw sewage through natural bacterial action. Therefore, the regulations in Annex IV of MARPOL 73/78 prohibit the discharge of sewage into the sea within a specified distance from the nearest land, unless otherwise provided. States are required to ensure the provision of adequate reception facilities at ports and terminals for the reception of sewage, without causing delay to ships [6]. Annex IV of MARPOL 73/78 requires that all ships should be equipped with approved sewage treatment plant or comminuting and disinfecting system or holding tank [5]. Firmer requirements are set for passengers ships shipping in Baltic Sea. New passenger ships when operating in the Baltic sea on or after 1 June 2019 and existing ships when operating on or after 1 June 2021 and intending to discharge treated sewage effluent into the sea [7] have to use sewage treatment plants where the geometric mean of the total nitrogen and phosphorus content of the samples of effluent taken during the test period should not exceed total nitrogen: 20 mg/l or at least 70 % reduction and total phosphorus: 1.0 mg/l or at least 80 % reduction [8].

Also, States must take the measures provided in Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1992 (Helsinki Convention) Annex IV. The Convention sets requirements for treated sewage discharge into the sea and requirements for sewage system volume and location, taking into account the specific needs of passenger ships [1].

3. Pollution of Sewage in the Baltic Sea

Water pollution can be divided as follows:

1) Chemical pollution. It can be inorganic and organic. From inorganic substances water is contaminated with various salts, acids, alkalis, heavy metals, but from organic – technical organic substances such as oil and its products, surface active agents (detergents), pesticides, organic substances of natural origin – such as plant and animal metabolism products [9].

2) Physical pollution. It is thermal contamination that increases the water temperature. It adversely affects
the biological processes of waters, as the rise in temperature is detrimental to many aquatic organisms that can live within a certain temperature range [9]. The temperature of the sewage is warmer than the normal water temperature, except during the warmest months and it rarely freezes owing to high conductivity. The temperature of raw sewage ranges from 8–12°C in winter to 17–20°C in summer. These variations in temperature can markedly influence the makeup of microbial communities. Optimum temperatures for bacterial activity are in the range from 25 - 35°C. Aerobic digestion inhibited if the temperature raised to 50°C [10].

3) Biological pollution. It consists of animals, plants, bacteria, fungi and viruses that are not characteristic of the water object in the water. The bacteriological contamination of water is characterized by the amount of intestinal or coli bacteria (Escherichia coli) in water. The presence of coli bacteria shows that there are faeces or animal faeces in the water and therefore other pathogenic microorganisms, viruses and pathogens are possible [9].

Biological elements of water pollution are specified by the presence of nitrogen compounds as total nitrogen (N_{total}), nitrate nitrogen (NO_3^{-1}), nitrite nitrogen (NO_2^{-1}) and ammonium nitrogen (NH_4^{+1}); the presence of phosphorus compounds characterized by total phosphorus (P_{total}), orthophosphate (PO_4^{3-}) [9].

Fig. 1 Scheme of internal feedback processes slowing down the recovery from eutrophication in the Baltic Sea from ships sewage (adapted from Vahtera et al., 2007, [11])

The Baltic Sea ecosystem is strongly influenced by nutrient loading from the outside [11], long nutrient decomposition time and high buffer capacity in a system that slows down nutrient load reduction [12], water temperature differences between layers, salinity differences between open sea parts and basins [2], light conditions at different depths of the water layer, ice conditions in the winter period in the sea and its basins, freshwater inflow in the Baltic Sea and bays [13].

One of the facilitators of the supply of substances in external feeds in the Baltic Sea is sewage discharge by ships. Toilet sewage is the main source of nutrients. On passenger ships also other sources of nutrients in wastewater exist, as ground food waste that can reduce the nutrient load.

In the Baltic Sea, cruise ships spend more than 7.15 million man-days a year and carry more than 40 million ferry passengers a year on international routes. Based on the estimations of the nutrient content of daily toilet sewage per person (thus excluding other potential sources of nutrients) and person days on board cruise ships operating in the Baltic Sea, the total annual nutrient content of toilet sewage from cruise ships can be roughly estimated at 86–107 tonnes of nitrogen and 30–36 tonnes of phosphorus, depending on the figures used for nutrient content of daily toilet sewage per person. In addition, sewage is produced by the 40 million passengers on board international ferries as well as the uncalculated number of voyages by smaller ferries and leisure boats [14].

The increasing load of nitrogen compounds and phosphorus compounds from the outside, as well as differences in the molar ratio of the load velocities of these compounds in the water surface, is the reason for the increase of organic matter or phytoplankton algal biomass, which reduces water clarity. On the other hand, when organic material from the upper layers of water reaches the seabed, it consumes more oxygen when it decomposes. The result is oxygen free condition. Groundwater hypoxia (oxygen concentration <2 mg / l) and anoxia (oxygen concentration = 0), as a matter of eutrophication in coastal waters [11]. The process of internal nutrient feedback is slowing down the Baltic Sea recovery (see Fig. 1).

4. Port Reception Facilities

Port reception facilities (PRFs) are stationary, floating, or mobile facility that can receive ship-generated waste and cargo residues [13]. Stationary equipment is a sewage pipe leading to a shore-based sewage treatment plant, and the vessel is connected to it by a standard discharge hose. As the system is fixed, the reception capacity can be very high, reaching several hundred cubic meters per hour. Portable devices can be a sewage tank on a truck or barge. Systems
benefit is mobility, but capacity can be limited [3]. Receiving all sewage via a mobile PRF inevitably leads to problems with discharge speed and capacity for both ports and passenger ships. At smaller ports that can only provide tank trucks and/or barges for the reception of sewage, technical issues can cause more severe consequences. Connecting and disconnecting multiple times increases the risk of incidents. Unpleasant odors often negatively impact passengers. The availability and deployment time depend on tank truck or barge provider and can, therefore, lead to unforeseen delays[15].

In 2016, the HELCOM Working Group and the International Cruise Line Association (CLIA) conducted a study on the feasibility of implementing the requirements of Annex IV to MARPOL 73/78 by organizing passenger ship effluent operations in the Baltic Sea during the annual cruise. In this study, both cruise ship operators and ports were invited to document their experience [14]. During 565 port calls investigated, 220 issues were reported by the cruise ships:

- No facility available (12.7%);
- Use of facility technically not possible (5.9%);
- Undue delay (21.8%) [15].

Also, there is a growing tendency for cruise ships to stay in ports for between 32 and 36 hours, thus increasing the amount of wastewater generated [15]. In 2017 HELCOM carried out a questionnaire that was developed by PIA (“Prüfinsitut für Abwassertechnik”) for port authorities and municipal wastewater treatment plants (MWTP) to determine the current state of PRFs and to identify problems of receiving sewage from passenger ships and the PIA questionnaire showed that 38% of the surveyed ports had problems with the connected MWTP. Small ports with poor infrastructure are affected, but major ports may have problems when several ships start to discharge at the same time. Some MWTP is designed to receive sewage mainly from households and are mainly equipped for reducing carbon and nutrients. They are not prepared to treat sewage mixed with oil and other substances like chlorine.

Therefore, sewage from ships will most likely be classified as industrial waste and not as household sewage once it is discharged in the port [15]. All these facts call for a focus on the treatment of passenger ship effluents on board and biological treatment on board can reduce MWTP load.

5. Biological Sewage Treatment Methods

Depending on the treatment process, the treatment plant can be divided into:

1) Pre-cleaning removes solid and liquid water-soluble substances. After filtering the water, it retains a significant number of suspended particles, which are heavy and precipitate by gravity. Primary water treatment significantly reduces the biological oxygen content (BOD) and suspended solids content of wastewater.

2) Secondary treatment is based on the biodegradation of dissolved and remaining suspended organic matter with the help of specialized microorganisms. They can effectively decompose organic matter and provide optimal conditions for development, first by supplying oxygen, but also, if necessary, by ensuring optimal temperature regimes, pH, salt and nutrient content.

3) Special purification completely removes unwanted substances. During it, suspended solids, dissolved organic matter, nitrogen compounds, phosphorus compounds, metal ion ions, inorganic salts and microorganisms are removed [9].

Wastewater treatment methods can divide into mechanical, chemical or biological. In practice, these methods are combined. The most common combinations are mechanical-chemical, mechanical-biological, and chemical-biological [4]. Biological wastewater treatment is based on the type of effluent and the concentration of organic matter (either chemical oxygen demand (COD) or BOD) [16]. The activated sludge (ASP) method is one of the most common methods of wastewater treatment. ASP is an aeration tank that stops the growth of bacterial biomass. Oxygen can be supplied by diffuse or suspended aerators [16]. Activated sludge is a culture of microorganisms that forms dispersion in the aquatic environment by coating the particles of organic matter - sludge. Activated sludge is an artificial biocenosis consisting of bacteria, fungi, yeasts, protozoa, etc. [9], the predominant organism is bacteria (around 300 species). The bacterium is one of the smallest and richest living organisms. Each has one cell with a size of about 0.5-2 μm [17]. In the process of purification, the biomass of microorganisms increases rapidly. Therefore, the part that settles to the bottom of the aeration tank is removed. After the aeration tank, the treated water is settled by separating the precipitated activated sludge mass [9].

Wastewater treatment can also be performed using a fixed bed method, such as spray filters or biological reactors. Anaerobic sludge upstream reactors (UASB) is a stable technology that has been operating effectively in wastewater treatment for several decades. This technology reduces energy consumption and sludge production [16]. UASB is a high-speed reactor without moving parts. The reactor is equipped with deflectors (degassing). There is accommodation above the deflectors. It is used to collect the gas produced in the reactor. The reactor is closed at both ends to maintain anaerobic conditions [18].

The biofilter (BF) is one of the main biogas waste and odor prevention methods used effectively in the petrochemical and tobacco industries. BF is also used for wastewater treatment and it has lower operating costs, efficient processing power and convenient maintenance. Biofilters consist of a container of organic material cultured with microorganisms. Nutrients are supplied and suitable conditions are provided for biofilm development activity and maintenance of viability. During spraying, the wastewater mixes with air and dissolves oxygen. When wastewater is filtered through a BF, the bacteria purify the water. As the microorganisms are constantly growing on the biofilm,
obsolete microorganisms sink to the bottom of the BF, where they are periodically removed [16].

Microbial fuel cells (MFCs) can decompose very complex waste streams/contaminants that can be mineralized more efficiently than conventional treatment processes [16]. The MFC consists of a cathode, an anode, a proton exchange membrane, and a resistor. Electrons move to the anode through the resistor. The anode is in a consortium of bacteria and may also contain oxidizable organic material or a fuel source. Oxidation occurs in the anode. The protons then pass through a proton exchange membrane to the cathode (provided with the desired source microbes), where they enter water [17].

The Moving Bed Biofilm Reactor (MBBR) is probably the best alternative to ASP in terms of nutrient and organic carbon removal. MBBR is more compact than ASP, so it reduces the costs- lower operation, maintenance, and replacement costs. This process can be used for new wastewater treatment plants or for upgrading existing wastewater treatment plants and increasing the ship's eco efficiency. The effectiveness of MBBR depends on the percentage of biofilm carriers in the container, the surface area of the bio circulation, the aeration and the amount of organic matter. The added biomass in the biofilm-based process creates the ability to operate at high concentrations of active biomass, which increases the rate of biodegradation and makes them more resistant to congestion and toxic compounds. In biofilm processes, biomass can be specialized for specific processing purposes. For example, nitrification and denitrification can be successfully achieved in biofilm-based processes because the biofilm retains nitrates as they are slower growing microorganisms. An important feature of MBBR is the biofilm carrier. Biofilm carriers can vary in size and shape depending on the intended use. The efficiency of the biofilm carrier is influenced not only by the shape, but also by the surface area and the conditions under which the carrier is in the bioreactor [16, 18].

Packaged bioreactors (PBR) are tubular tanks filled with solid catalyst particles that have a high nutrient exchange in terms of weight. The catalyst is packed in a column and fed from the bottom or top of the reactor, and the exchange capacity depends on its content and not on the size of the reactor. Packaging materials are very important for the effective immobilization of bacteria in the formation of biofilms for treatment [16].

Anaerobic membrane bioreactor (AnMBR) is a combination of the anaerobic biological wastewater treatment process as ASP and membrane filtration. The system acts as the integration of suspended biomass growth and ultrafiltration (UF) or microfiltration (MF) membrane systems. The biological part of the reactor is used for biodegradation and the membrane compartment is responsible for retaining suspended solids, including suspended biomass and inert solids. AnMBR can achieve complete separation of the solid's retention time from the hydraulic retention time. The system is also not affected by wastewater properties, biological process conditions and sludge properties [19].

6. Biological Treatment Method used in Ships Sewage Treatment Systems

Studies of ships sewage treatment plant effectiveness have not been identified during this study. Also, different biological treatment methods in ship treatment plants have not been compared. COD or BOD can be used to compare biological methods. BOD describes the amount of dissolved oxygen consumed by the bacteria by oxidizing the organic matter present in the water sample. This indicator is determined by the sample's five-day incubation period at 20°C, where the sample is placed in the dark. COD is the amount of oxygen required for the complete chemical oxidation of organic matter to carbon dioxide. COD is an indicator of the mass concentration of organic compounds [20]. According to the guidelines issued by IMO Resolution MEPC.227 (64), the permissible BOD concentration at the discharge from the ship’s sewage treatment plant should not exceed 25 mg/l, while COD should not exceed 125 mg/l [8].

<table>
<thead>
<tr>
<th>Parameter/ [mg/l]</th>
<th>Average BW concentration on cruise ship1</th>
<th>Average BW concentration on cruise ship2</th>
<th>Average BW concentration on cruise ship3</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>1140</td>
<td>6325</td>
<td>7400</td>
</tr>
<tr>
<td>BOD5</td>
<td>526</td>
<td>3475</td>
<td>3700</td>
</tr>
<tr>
<td>Ntot</td>
<td>-</td>
<td>850</td>
<td>-</td>
</tr>
<tr>
<td>Ptot</td>
<td>18.1</td>
<td>78.25</td>
<td>160</td>
</tr>
</tbody>
</table>

Fig. 2 Composition of black water 1) Based on data collected by the EPA in 2004 and 2005, when Black water is mixed with grey water, 2) Based on data collected by the TUHH in 2015, 5 Ships 13 samples, 3) Based on data collected by Ohle P. et al., 2009

<table>
<thead>
<tr>
<th>Parameter/ [mg/l]</th>
<th>Average GW concentration on cruise ship1</th>
<th>Average GW concentration on cruise ship2</th>
<th>Average GW concentration on cruise ship3</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>1890</td>
<td>1000</td>
<td>1150</td>
</tr>
<tr>
<td>BOD5</td>
<td>1140</td>
<td>354</td>
<td>865</td>
</tr>
<tr>
<td>Ntot</td>
<td>-</td>
<td>-</td>
<td>22</td>
</tr>
<tr>
<td>Ptot</td>
<td>10.1</td>
<td>3.34</td>
<td>6.48</td>
</tr>
</tbody>
</table>

Fig. 3 composition of grey water 1) Based on data collected by the EPA in 2004, 2) Based on data collected by the ASCI, 3) Based on data collected by the TUHH)
According to studies about ships’ sewage composition, it was researched that BOD concentration varies from 3475 mg/l to 3700 mg/l in black water, but in grey water concentration varies from 354 mg/l to 865 mg/l. COD varies from 6325 mg/l to 7400 mg/l in black water and 1000 mg/l to 1150 mg/l in grey water (see Fig. 2 and Fig. 3) [15]. It can be concluded that untreated black water BOD can be around 140 times bigger and untreated grey water BOD can be around 25 times bigger than permissible BOD concentration. As per COD concentration, for black water this amount can be up to 110 times bigger, but for grey water concentration can be up to 9 times bigger than it is required. As per total nitrogen, conclusions can be disputable, as only one measurement is found. Total phosphorus average content in untreated black water can reach up to 85 times and in grey water up to 7 times more than it is set.

Fig. 4 Schematic illustration of the passenger ship sewage treatment setup including a moving bed biofilm reactor and granulated active carbon filter for disinfection

Based on the findings of the study, these concentrations in passenger ship sewage could be reduced through an eco-design approach, focusing on a mobile bed biofilm reactor and eco-friendly disinfection, as one of the methods-granulated active carbon. The ship’s sewage treatment system, shown in Fig. 4, may be capable of treating the effluent to such an extent that the treated water can be reused for technical purposes, thus improving the eco-efficiency of the ship.

7. Conclusion

To promote the recovery of the Baltic Sea from eutrophication, stricter requirements have been set for the discharge of sewage from passenger ships operating in the Baltic Sea. The reception of sewage from passenger ships may not meet the new requirements, so the focus is on wastewater treatment on board, improving its eco-efficiency. Wastewater treatment plants are divided into three groups according to their treatment process: primary, secondary, and special treatment. They are divided into mechanical, chemical, and biological. Secondary treatment is usually based on biological or chemical methods. The theoretical analysis shows that portable biofilm reactors (MBBRs) are a better alternative to the most used activated sludge method on board.

Based on the results of the study, a schematic diagram for a passenger ship wastewater treatment system was developed. It includes a mixing tank (mechanical cleaning), a moving bed biofilm reactor and eco-friendly disinfection. Such a treatment system could treat wastewater to such an extent that the treated water can be reused for technical purposes, thus improving the eco-efficiency of the ship.

Acknowledgements

This work has been supported by the European Regional Development Fund within the postdoctoral (postdoc) project “Green technology solutions for enhancing the eco-efficiency of ships for the sustainability of the Baltic Sea environment and reducing human health risks” No.1.1.1.2/VIAA/3/19/477

References


Closed Power Loops in the Guidance of Vehicles by Railway Track System

V. Tkachenko¹, S. Sapronova², E. Zub³, M. Morneva⁴

¹State University of Infrastructure and Technologies, Kyiv, Ukraine, E-mail: v.p.tkachenko@ukr.net
²State University of Infrastructure and Technologies, Kyiv, Ukraine, E-mail: doc.sapronova@gmail.com
³State University of Infrastructure and Technologies, Kyiv, Ukraine, E-mail: epzub@ukr.net
⁴Volodymyr Dahl East Ukrainian National University, Severodonetsk, Ukraine, E-mail: morneva@gmail.com

Abstract

The guidance vehicle by railway track is associated with a number of complex physical processes of interaction between wheelsets and rails. The lateral interaction between wheel flanges and rails is described by stability theory. Longitudinal reactions in wheel-rail contacts are studied in the theory of adhesion. However, there are a number of limitations to the classical idea of the process of guidance vehicle by railway track. Until now, the properties of two- and multi-flow power transmissions in the vehicle-track system have not been taken into account. For example, a two-flow view has a power transmission of binding force in two-point contact (flanges) contact of the wheel and rail. In this case, there is a closed power circuit with nodal points in the main and flanges contacts. The characteristic for closed power circuits in wheel-rail contacts is parasitic sliding, which is the cause of additional power losses and wears on the rolling surface of wheels and rails. Wheelsets and rail together form separate closed power circuits. The contacts of the wheels with the rails are the nodal points in the power circuits “rail–wheel–axis–wheel–rail–sleeper”. Parasitic power flows can occur in interaxle closed power circuits of bogies. Parasitic power circulation in closed power circuits can reach significant values and is the cause of additional resistance to the movement of vehicles. The authors classify this resistance as “kinematic resistance to motion”. The authors simulated the interactions of wheelsets and the track when moving in a curve.

In the process of modeling the interaction of wheelsets and the rail track, the parasitic power characteristics in the power circuits of the guidance vehicle by railway track system were obtained

KEY WORDS: railway track, railway vehicle, guidance by the railway track, controllability, control effector, closed power circuits, adhesion, resistance to motion

1. Introduction

The term “guidance of vehicle by railway tracks” has an analogue – “controllability” or “handling” in the theory of motion of wheeled and tracked vehicles, water and aircraft, spacecraft [1]. Controllability – the property of a vehicle to change motion parameters during a control action. These parameters, first of all, are the trajectory of movement and speed. In the presence of control effector, controllability is defined as the reaction of the machine in the form of changes the directional or transverse movement parameters to the control effect from the side of the control.

In the presence of controls, controllability is defined as the reaction of the machine in the form of the directional and lateral motion parameters change to the action of the control effector. For example, in the case of a car, this effect is the rotation of the steering wheel; in the case of an airplane, a wheel controller or pilot control stick, etc. [2].

For railway vehicles, only the rail track can be such a control effector. Changing of movement trajectory (guidance) of the vehicles is carried out by the rail track by means of horizontal – lateral and longitudinal – track reactions of the rails on the wheelsets.

Lateral guiding forces at flanges contacts and longitudinal adhesion forces (creep forces) at the wheel-rail contacts on rolling surfaces are such reactions.

Lateral reactions in flanges wheel-rail contacts are studied in a large number of researches on the horizontal dynamics and stability of movement of rail vehicles.

At the same time, the role of longitudinal guiding forces has not been sufficiently studied. This is especially true for researches on the influence of the guidance of wheelsets by railway tracks on the resistance to motion. Ignoring the controllability characteristics of rail vehicles can cause an unjustified increase in the operation of frictional loads in wheel-rail contacts and, as a consequence, additional resistance to movement [3, 4]. Operational data can indirectly confirm that the wear of the flanges and side surfaces of the railheads can be so threatening that it causes “rail plague”.

The study of the controllability of rail vehicles in the form as it is considered in the theory of the movement of wheeled vehicles is a trivial task, since in this case, control according to a rigid program takes place and its result, except for cases of the derailment, is known in advance within the clearances of wheelsets in a rail track. The guiding forces in the wheel-rail contacts are the control action for traditional carriage structures moving along the track without the influence of the operator or the control system. Controllability criteria are associated with an additional action on the vehicles from the rail track, as a control effector, and on the track in the form of the vehicle's response to the control action associated with the control process [5].
The power factors in the "vehicle–track" system can be classified as guiding factors and resistance factors. However, this classification is conditional, since one and the same factor, in different motion modes or even in different wheelsets, can have the character of both a guiding factor and a resistance factor.

It is proposed to evaluate the rail vehicle controllability by two quality indicators.

The first is the horizontal impact on the track. It is necessary to distinguish between two motion modes, when the vehicle is guided by a rail track: the kinematic guidance mode, in which none of the wheelsets has flange wheel-rails contact, and the force guidance mode, which is characterized by the flange contact of the wheels with the rails. Obviously, in the kinematic guidance mode, the level of the vehicle's impact on the track will be lower than in the force guidance mode.

The second quality indicator of controllability is additional resistance to the movement associated with the guidance of the vehicles by rail track. The authors of [6] called the resistance to motion caused by the guidance of the vehicles by the rail track – the kinematic resistance to motion.

2. Closed Power Circuits in the System of Guiding Carriages by Rail Vehicles by the Rail Track

2.1. Closed Power Loops in the Wheelset Drive

Often branching power circuits in mechanical power transmissions form closed power circuits. The directions of the power flow of the circuits can coincide or be the opposite.

In the first case, we have an uneven distribution of flows along the branches. In the second, the circulation of the power flow within the circuit.

Circulating loop power flows are typically parasitic and can have two main consequences. First, an increase in the load on one of the branches of the circuit in N or more times (with N-stream transmission) in comparison with the average value of the flow with their uniform distribution. Secondly, in the presence of damping elements in the circuit, the overall efficiency of the power train decreases.

Therefore, when designing mechanical transmissions, they try to avoid closed power circuits. However, in technology there are known examples of the application of multi-stream power transmissions for which closed power loops are characteristic. An example of such a transmission is a double-sided drive of a wheelset electric locomotive. In the separate drive of electric locomotive wheelsets, a double-sided gear transmission is traditionally used (Fig. 1). It is considered that it should provide equal torques on the wheels of the wheelset. For this, the gearing is made helical with the opposite inclination of the teeth, as in a chevron gear train. However, self-centering of such a transmission is possible only under stationary conditions. In motion in a locomotive running gear, as is known, there are high levels of dynamic forces and significant relative displacements of the transmission elements. Even an insignificant lateral displacement of the wheelset relative to the traction motor (TEM) leads to the emergence of circulating power flow in a closed circuit “TEM - gear train - axle - gear train - TEM”. This can cause significant additional loads on the gear teeth. In addition, in spite of the high efficiency of gears, the level of energy losses in the circulating power flow can reach 1 ... 2% of the traction motor power.

![Fig. 1 Double-sided separate drive of a wheelset electric locomotive scheme: 1 – traction motor; 2 – wheelset; 3 – thrust actuators – cylindrical helical tooth gear](image)

![Fig. 2 Scheme of two-point wheel-rail contact: C1, C2 – the main and flange contacts; S1, S2 – adhesion forces in contacts; R1 – radius of the main and flange contacts; V – the direction of movement; W – resistance to movement](image)

2.2. Closed Power Loops in Wheel-Rail Contacts

The circulation of flows in closed power circuits in the truck of rail vehicles is typical. A biaxial locomotive bogie is such an example. There are several closed power circuits in the bogie. Firstly, these are closed power circuits in wheel-rail contacts with two-point (flange) contact (Fig. 2).

On Fig. 2: C1, C2 – the main and flange contacts; S1, S2 – adhesion forces in contacts; R1 – radius of the main and flange contacts; V – direction of movement; W – resistance to movement. For the scheme in Fig. 2 the following equations are valid:

\[ S_1 \cdot R_1 = S_2 \cdot R_2 \]  \hspace{1cm} (1)
\[ W = S_1 - S_2 \]  \hspace{1cm} (2)

From (1) and (3) it follows that the additional resistance to motion at two-point wheel-rail contact is equal to:
Thus, in case of flange wheel-rail contact, closed power circuits between the main and flange contacts are the cause of parasitic slippage and, as a consequence, leads to the appearance of kinematic resistance to motion. An indirect confirmation of this is the squeal of the wheels when driving in curves of a small radius [7]. This can often be seen on the tram as an example.

2.3. Closed Power Loops of Wheelsets

The second type of closed power circuits are wheelsets [8-9]. When a wheelset is rolling on a rail track, each of its transverse position relative to the track axis corresponds to a different rolling radius of the wheels. The difference in the radius of the left and right wheels of a wheelset depends on the profiles of the wheels and the lateral displacements of the wheelset in the track. For each lateral position of the wheelset, it is possible to determine the instantaneous turning radius at which it can roll without slipping in the wheel-rail contacts and without flange contact. In this case, the rolling trajectory of the wheelset can be called equilibrium. However, due to the interaction between the wheelsets in the bogie, the existent rolling trajectory of the wheelset differs from the equilibrium trajectory. According to the principle of distribution of torque to the wheels, even a separate drive of wheelsets is a multibelt drive. The rigid connection between the wheels of the wheelset leads to parasitic slippage in the contacts and the circulation of energy in the circuit “left wheel – axle – right wheel – right rail – sleeper grid – left rail – left wheel” (Fig. 3). An additional component of the kinematic resistance to movement is a consequence of parasitic slippage in the wheel-rail contacts. The energy of the force flow circulation is absorbed in the wheel-rail contacts, as the wear energy of the wheels and rails. The energy of the circulation can be partially absorbed in the lossy elements of the bogie.

![Fig. 3 The closed power circuit “left wheel – axle – right wheel – right rail – sleeper grid – left rail – left wheel”](image)

The uneven distribution of the power flow between the wheels depends on several factors:
- the stiffness factor of the adhesion characteristics;
- torsional stiffness of the axle, i.e. wheel coupling parameters;
- the geometric characteristics of the wheelset, including the taper and diameter of the wheels, the gage, the base of the vehicle;
- parameters of longitudinal and transverse connections of wheelsets with the bogie frame.

3. Fundamentals of the Closed Force Loops Theory as Applied to the Guidance of Vehicles by a Railway Track

3.1. The Concept of Power Flows

Energy conversion in a mechanical transmission can be represented schematically in the form of power flows. Power flow is a physical quantity that is numerically equal to the mechanical work transmitted by forces or rotational moments applied to the moving links. Power flows change (separation or fork) at the nodal points.

A binding force flow is called a flow that connects the nodal points without changing the intensity. The intensity of the binding flow is equal to the power of forces or moments transmitted through the element of the kinematic chain:

\[
 f_i = F_i \cdot V_i \quad \text{or} \quad f_i = M_i \cdot \omega_i ,
\]

where \( F_i, M_i \) – force or rotational moment of the force flow; \( V_i, \omega_i \) – linear or rotating speed.

Accumulating flows are associated with the presence of potential energy accumulators in the kinematic chain. Usually, these are mechanical elastic elements – springs, torsion bars. The intensity of the accumulating flow depends
on the stiffness \( (C) \), deformation \( (\Delta) \) and deformation rate \( \left( \frac{d\Delta}{dt} \right) \) of the elastic element:

\[
a_i = C \cdot \Delta \cdot \frac{d\Delta}{dt}. \quad (5)
\]

Dissipative flow occurs when there is a damping element at the nodal point. Dissipation intensity \( (d) \) depends on the characteristics and type of damping. In the case of a classic hydraulic damper:

\[
d_i = \beta_i \cdot \left( \frac{d\Delta}{dt} \right)^2, \quad (6)
\]

where \( \beta_i \) is the damping coefficient of the linear damper.

For friction-type damper:

\[
d_i = \text{Ffriction} \cdot \text{sign} \left( \frac{d\Delta}{dt} \right) \frac{d\Delta}{dt}, \quad (7)
\]

where \( \text{Ffriction} \) – damper friction force.

Accumulating and dissipating power flows connect the nodal points with the external environment, and the dissipating flows always have a negative value. Fig. 4 shows a diagram of the power flows of a separate wheelset drive. The position of the wheelset is considered when one of the wheels has two-point contact with the rail. Nodal point 0 depicts the branching of the power flow of the traction motor gearbox \( f_0 \) into two flows of the wheelset consoles to the wheels \( f_{01} \) and \( f_{02} \). Nodal point 1 depicts the branching of the force flow of the first wheel \( f_{01} \) into two flows: \( f_{1I} \) – to the main wheel-rail contact and \( f_{1II} \) – to the flanges wheel-rail contact. Nodal points I and II represent the two-point wheel-rail contact of the first wheel, and the nodal point 2 represents the wheel-rail contact of the second wheel. Nodal points I, II, 2 have output connecting flows \( f_{1I}, f_{1II}, f_2 \) – energy losses in wheel-rail contacts. Nodal point 3 represents a rail track and has output flows \( f_3 \) and \( d_3 \). The nodal points of the contour, connected directly to the input and output flows (points 0 and 3), are the input and output nodal points.

Power loops have the following properties.

- The sum of the force flows of the nodal point is equal to zero. In this case, the input streams are considered positive, and the output - negative. For example, for nodal point 3:

\[
\overline{f_{13}} + \overline{f_{23}} + \overline{f_3} = 0. \quad (8)
\]

- The sum of the external power fluxes of the circuit is equal to zero. For example, for counter 1–I–3–II:

\[
\overline{f_{01}} + \overline{f_{1I}} + \overline{f_{1II}} + \overline{f_{23}} + \overline{f_3} = 0. \quad (9)
\]

For a quantitative assessment of the level of circulation of power flows within the circuit, it is proposed to use the circulation coefficient, which can be determined for any selected circuit by the formula:

\[
\lambda = 1 - \sum_{i=1}^{n} f_i \left( \sum_{i=1}^{n} |f_i| \right). \quad (10)
\]

In accordance with the concept of the circulation of power flows in closed loops, circulation flows with a power level independent of the drive power are possible. To certain limits, especially under oscillatory loading conditions, a decrease in the rigidity of the elements of the power circuit makes it possible to reduce the level of the power circulation. However, in stationary transmission modes, the limitation of the contour flows can be carried out only with the help of decoupling nodal points. Depending on the type of decoupling nodal points in the contours, conditions arise for the formation of circulating flows with different characteristics.

### 3.2. Types of Decoupling Nodal Points

Decoupling nodal points in drives are either provided constructively to limit internal forces in the transmission (design decoupling points) or arise in connection with system functions (functional decoupling points).

Design decoupling points, for example, include differential decoupling points, which come in several flavors: equal (equal distribution), unequal (unequal distribution), and bounding.

Equal decoupling points distribute flows equally among the branches. A typical example of an equal decoupling
nodal point is a differential gear mechanism (differential) of the main drive of the wheels of a car. The characteristic operating mode of the differential is the separate slip mode, which occurs when one of the branches of the circuit is unable to absorb the flow in a stationary mode. A typical example of an equal decoupling point is a differential gear mechanism (differential) of the main drive of the wheels of a car. The characteristic operating mode of the differential is the separate slip mode, which occurs when one of the branches of the circuit is unable to absorb the flow in a stationary mode.

Unequal decoupling points ensure the distribution of flows along the branches in accordance with the gear ratios \( k_1, k_2, ..., k_n \):

\[
    f_{i0} = k_i \cdot f_i; \quad f_{2i} = k_2 \cdot f_i; \quad ... \quad f_{ni} = k_n \cdot f_i, \quad \text{and} \quad \sum_{j=1}^{n} k_j = 1; \quad \sum_{j=1}^{n} f_{ji} = f_i. \tag{11}
\]

An example of an unequal decoupling point is a differential transfer gearbox.

Limiting decoupling points are characterized by a trigger threshold, i.e. limiting force flux, at which an ordinary nodal point turns into a decoupling nodal point. Usually, the trigger threshold is defined as the difference between the output streams. For example, for a two-flows output of the \( i \)-th point: \( \Delta f = f_{oi} - f_{2i} \). Known designs of differential mechanisms with internal friction, which is introduced to reduce the likelihood of separate slipping. In this case, the trigger threshold corresponds to the static friction force in the limiting torque clutch. Limiting decoupling points generally have mechanical losses with energy dissipation.

Energy losses in closed power circuits are determined by the power of the dissipating power flows. The loss performance depends on the type of decoupling points. In the general case, the scattering flux is defined as the power of the friction forces. The efficiency of a transmission containing \( n \) closed power circuits can be determined from the formula:

\[
    \eta = 1 - \frac{\sum_{i=1}^{n} d_i}{f_0}, \tag{12}
\]

where \( f_0 \) – is the input power flow; \( d_i \) – scattering fluxes of the circuits.

4. Conclusions

The authors have demonstrated a new scientific approach to the analysis of the dynamics of the guidance of vehicles by railway track. The approach is based on the description of dynamic processes using force flows.

To some extent, improvement of the controllability characteristics of rail vehicles for movement in straight lines and curves of a large radius can be achieved by optimizing the parameters of traditional structures: by choosing a rational wheel profile; bogie bases; characteristics of longitudinal and transverse connections of wheelsets. However, this approach is not effective for curves of medium and small radius. In this case, a significant improvement in controllability can be achieved only due to unconventional design solutions of the elements of the carriage.

The application of the closed power loops theory makes it possible to find the elements of the guidance of vehicles by railway track system, which can be modernized. In particular, the efficiency of the alignment of radially mounted wheelsets with free-running wheels can be assessed. Such a constructive solution allows, due to the introduction of decoupling nodal points into the closed power circuits, to minimize the level of circulation in the contact circuits and to reduce the kinematic resistance to movement, in comparison with the traditional options.

References


The Forecasting of Government Revenues in Poland in the Aspect of Security

B. Kozicki¹, M. Górnikiewicz²

¹Military University of Technology, Kaliskiego 2, 00-908 Warsaw 46, Poland, E-mail: bartosz.kozicki@wat.edu.pl
²Military University of Technology, Kaliskiego 2, 00-908 Warsaw 46, Poland, E-mail: marcin.gornikiewicz@wat.edu.pl

Abstract

In this article the authors raise the forecasting of government revenues in Poland for 2020 in the aspect of security. The research was initiated with the definition of primary series. Due to the critical analysis of literature and the relationships noticed in the course of the research, two methods were selected for the forecasting of data concerning government revenues in Poland for the future dynamically. Then, the primary series was divided into two parts: the teaching part including 120 elements and the testing one including 17 elements. The teaching time series was forecast for seventeen future periods with two methods. The forecasts were analyzed with the application of such research tools as: linear graph juxtaposing data related to the teaching time series and the forecasts and the analysis of the mean absolute percentage error. The best method proved to be Holt-Winter’s exponential smoothing which was used to forecast primary data for 2020. The forecasts obtained were analyzed and evaluated.

KEY WORDS: forecasting, government revenues

1. Introduction

The premise for undertaking research is the lack of literature related to forecasting budget revenues of Poland in dynamic terms.

The purpose of the article is an attempt to forecast data on the Polish budget revenues for 2020 in the aspect of security. The subject of the research will be the revenues of the Polish budget, the object of the research will be the area of the Republic of Poland.

The article uses research methods in the form of literature analysis which deals with issues related to forecasting, budget revenues, analysis of source documents and comparison. Moreover, the following research tools were used: quartile chart, autocorrelation, partial autocorrelation, multiple regression, histogram.

2. Literature Analysis

As a result of a critical analysis of the literature [1] and the authors’ own experience, it has been noticed that the revenues of the Polish budget come from other entities and that their acquisition by public authorities is final [10]. The state is not able to generate revenues on its own, which is why it uses the monetary revenues of other entities of the economic system, in particular the household income [9]. Revenue is the basic form of financial resources collected on the accounts of public funds [13-15]. They are grouped according to the budget classification which is based on three criteria: subject, object and type. In Poland, four main classifications of the budget revenues are used: parts, divisions, chapters and paragraphs.

Critical analysis of the literature made it possible to notice that the largest items of revenues of the Polish budget as a result of the critical literature analysis are: taxes, profit earned by the National Bank of Poland, profit of entrepreneurs and sole shareholder Treasury companies [Parlińska A., 2010, p. 127].

The article attempts to forecast budget revenues on a monthly basis for 2020 by using two forecasting methods. Forecasting in the literature is interpreted differently.

The analysis of the literature shows that "Forecasting is based on regularities characterizing the forecast phenomenon or occurring within them and other phenomena in the past or assumed in the future" [Dittmann P. et al., 2016, p. 21]. Many authors believe that forecasting is a sequential process [5-8]. According to M. Cieśliak [2] and A. Zeliaś [12] forecasting is understood as rational and, at the same time, scientific prediction of future events. On the other hand, J. Greń states that "forecasting is a practical activity aimed at formulating a scientifically justified assessment, i.e. an estimate of probable future conditions on the basis of past data and substantive knowledge about a given fragment of reality being the object of forecasting" [3]. According to E. Nowak, forecasting is a judgement related to the prediction of future phenomena based on scientific foundations [4]. In conclusion, it can be assumed that forecasting is a process of prediction, based on scientific foundations, the result of which will be a judgment on the state of the level of the future phenomenon under consideration.

It should be emphasized that the obtained forecasts may be useful during the planning process as well as in making economic decisions. According to many authors, forecasts allow a rational choice of the best course of action in the future [11], but they are not considered as plans, but only as planning information that may affect the definition of
The article analyzes and evaluates two forecasting methods in order to select the best one and obtain the forecast of 2020 budget revenues in Poland broken down by months. The research began with the analysis and evaluation of the original time series.

3. Forecasting

Fig. 1 summarizes data on the budget revenues of Poland between 2008-2019.

Visual observation of Fig. 1 made it possible to observe the existence of seasonality on a monthly basis and a growing trend. This became a premise for sketching the trend in the red line in Fig. 1 and describing the observed function with the formula in the footer.

As a result of critical literature analysis and observed relationships, two methods were adopted for forecasting in the future: Holt’s exponential smoothing and the SARIMA model. For research purposes, it was decided to choose the best method for forecasting or retrospective data on budget revenues for 2020. This became the premise for using the division of time series of primary data on budget revenues in between 2008-2019 into two parts: a teaching one with 120 elements and a testing one consisting of 17 elements. The original time series after the division is presented in Fig. 2.

The first method used to forecast a learner's time series for seventeen future periods was the SARIMA method. Then, the search for relevant predictors was performed. Significant predictors are summarized in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model:(0,1,0)(0,2,1) Seasonal delay: 12 Residual MS = .00497</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qs(1)</td>
<td>Parameter Asymptote Standard error Asymptote t(94) p Lower limit 95% confidence level Upper limit 95% confidence level</td>
</tr>
<tr>
<td></td>
<td>0,534158  0,075027  7,119554  0,000000  0,385191  0,683126</td>
</tr>
</tbody>
</table>

According to Table 1, the variable Qs - moving average row was an important predictor. The built model had the form of SARIMA: (0,1,0)(0,2,1) with a seasonal delay of 12. The next stage was to examine the residuals of the built SARIMA model. For this purpose, the following research tools were used: autocorrelation (Fig. 3), partial autocorrelation (Fig. 4), histogram (Fig. 5), and normality chart (Fig. 6).

The use of autocorrelation (Fig. 3) and partial autocorrelation (Fig. 4) testify to the existence of the phenomenon of white noise.
The use of research tools in the form of a histogram (Fig. 5) and a normality chart (Fig. 6) indicate that the distribution of residuals is not normal.

Then, in Fig. 7 and Table 2, the results of the forecasting of the teaching time series for seventeen future periods with the SARIMA model are summarized.
The evaluation of Fig. 6 is an indication of the seasonality and growing trend in the forecast of budget revenues in Poland.

<table>
<thead>
<tr>
<th>Observation no</th>
<th>SARIMA forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>121</td>
<td>43841,5</td>
</tr>
<tr>
<td>122</td>
<td>70357,2</td>
</tr>
<tr>
<td>123</td>
<td>98505,7</td>
</tr>
<tr>
<td>124</td>
<td>133834,0</td>
</tr>
<tr>
<td>125</td>
<td>164554,8</td>
</tr>
<tr>
<td>126</td>
<td>206627,5</td>
</tr>
<tr>
<td>127</td>
<td>236500,4</td>
</tr>
<tr>
<td>128</td>
<td>269720,2</td>
</tr>
<tr>
<td>129</td>
<td>300472,3</td>
</tr>
<tr>
<td>130</td>
<td>337456,6</td>
</tr>
<tr>
<td>131</td>
<td>369038,0</td>
</tr>
<tr>
<td>132</td>
<td>400454,5</td>
</tr>
<tr>
<td>133</td>
<td>53348,7</td>
</tr>
<tr>
<td>134</td>
<td>83320,2</td>
</tr>
<tr>
<td>135</td>
<td>116761,4</td>
</tr>
<tr>
<td>136</td>
<td>157175,0</td>
</tr>
<tr>
<td>137</td>
<td>193790,9</td>
</tr>
</tbody>
</table>

The highest forecast made by the SARIMA model was recorded in December - item 132 with the value of 400 454.5, and the lowest one in January - item 121 - the value of 43 841.5.

The second method used for forecasting was Holt-Winter’s exponential smoothing method. The results of the forecast for seventeen future periods are summarized in Fig. 8.

Visual observation of Fig. 8 allows us to state that the forecast made by Holt-Winter’s smoothing method has lower results than the forecast made by the SARIMA model. Detailed results of the forecast by Holt-Winter’s method with a breakdown by months (items 121 to 137) are presented in Table 3.
Table 3

Holt-Winter’s smoothing forecast for seventeen future periods

<table>
<thead>
<tr>
<th>Observation no</th>
<th>HW forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>121</td>
<td>35243,4</td>
</tr>
<tr>
<td>122</td>
<td>59649,0</td>
</tr>
<tr>
<td>123</td>
<td>84319,8</td>
</tr>
<tr>
<td>124</td>
<td>118434,1</td>
</tr>
<tr>
<td>125</td>
<td>144347,3</td>
</tr>
<tr>
<td>126</td>
<td>174126,6</td>
</tr>
<tr>
<td>127</td>
<td>206694,0</td>
</tr>
<tr>
<td>128</td>
<td>236618,5</td>
</tr>
<tr>
<td>129</td>
<td>266135,2</td>
</tr>
<tr>
<td>130</td>
<td>299675,1</td>
</tr>
<tr>
<td>131</td>
<td>331058,1</td>
</tr>
<tr>
<td>132</td>
<td>361288,2</td>
</tr>
<tr>
<td>133</td>
<td>36303,2</td>
</tr>
<tr>
<td>134</td>
<td>61438,0</td>
</tr>
<tr>
<td>135</td>
<td>86842,5</td>
</tr>
<tr>
<td>136</td>
<td>121968,7</td>
</tr>
<tr>
<td>137</td>
<td>148644,5</td>
</tr>
</tbody>
</table>

The highest forecast made by Holt-Winter’s method was recorded in December - item 132 with a value of 331 288.2 and the lowest one in January - position 121 - with a value of 35 243.4.

Then, analysis and evaluation of the residuals of the forecast made by Holt-Winter’s exponential smoothing method were performed. The following research tools were used for this purpose: autocorrelation (Fig. 9), partial autocorrelation (Fig. 10), histogram (Fig. 11) and normality chart with the Shapiro-Wilk test (Fig. 12).

![Autocorrelation of forecast residuals with the application of Holt-Winter’s method](image)

Fig. 9 Autocorrelation of forecast residuals with the application of Holt-Winter’s method

The evaluation of the research tools used in the form of autocorrelation (Fig. 9) and partial autocorrelation (Fig. 10) is the observation of the existence of the white noise phenomenon.
Visual observation of Figs. 11 and 12 allows us to state that the distribution of residuals of the forecast made by Holt-Winter’s exponential smoothing method is similar to the normal distribution.

Then, for the purposes of research, in Fig. 13 a comparative analysis of the testing time series was made with forecasts conducted with the application of the SARIMA model and Holt-Winter’s exponential smoothing method.

The evaluation of Fig. 13 is that the best-suited forecast for the testing series is Holt-Winter’s forecast. Then, analysis and evaluation of the mean absolute percentage error of forecasts made by the SARIMA model and Holt-Winter’s exponential smoothing method were performed (Table 4).
MAPE analysis of two methods: Holt-Winter’s and SARIMA

<table>
<thead>
<tr>
<th></th>
<th>MAPE HW</th>
<th>MAPE SARIMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0,043635</td>
<td>0,156886</td>
</tr>
</tbody>
</table>

The evaluation of the performed analyzes is that the best method is Holt-Winter’s exponential smoothing method because MAPE is the lowest and amounts to 4.36%.

This became a direct premise for applying the original time series of Holt-Winter’s exponential smoothing method in order to forecast the nineteen future periods.

The results of forecasting of the original time series for nineteen future periods with the use of Holt-Winter’s exponential smoothing method are summarized in Fig. 14 and Table 5.

![Fig. 14 Forecasting of the original series for nineteen future periods with the use of Holt-Winter’s exponential smoothing method](image)

The evaluation of Fig. 14 is the indication that the obtained forecast maintains tendencies from the past in the form of: trend and seasonality.

Table 5

<table>
<thead>
<tr>
<th>Observation no</th>
<th>Years</th>
<th>HW forecast</th>
<th>HW forecast (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>138</td>
<td></td>
<td>195 881,16</td>
<td></td>
</tr>
<tr>
<td>139</td>
<td></td>
<td>231 879,91</td>
<td></td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>265 419,99</td>
<td></td>
</tr>
<tr>
<td>141</td>
<td></td>
<td>298 260,36</td>
<td></td>
</tr>
<tr>
<td>142</td>
<td></td>
<td>336 095,02</td>
<td></td>
</tr>
<tr>
<td>143</td>
<td></td>
<td>371 075,54</td>
<td></td>
</tr>
<tr>
<td>144</td>
<td></td>
<td>405 113,45</td>
<td></td>
</tr>
<tr>
<td>145</td>
<td>2019</td>
<td>40 639,35</td>
<td>2 103 725,43</td>
</tr>
<tr>
<td>146</td>
<td></td>
<td>69 115,86</td>
<td></td>
</tr>
<tr>
<td>147</td>
<td></td>
<td>97 782,86</td>
<td></td>
</tr>
<tr>
<td>148</td>
<td></td>
<td>137 324,14</td>
<td></td>
</tr>
<tr>
<td>149</td>
<td></td>
<td>167 253,88</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td></td>
<td>201 421,12</td>
<td></td>
</tr>
<tr>
<td>151</td>
<td>2020</td>
<td>238 422,58</td>
<td>2 674 859,00</td>
</tr>
<tr>
<td>152</td>
<td></td>
<td>272 891,45</td>
<td></td>
</tr>
<tr>
<td>153</td>
<td></td>
<td>306 636,61</td>
<td></td>
</tr>
<tr>
<td>154</td>
<td></td>
<td>345 511,78</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td></td>
<td>381 448,16</td>
<td></td>
</tr>
<tr>
<td>156</td>
<td></td>
<td>416 411,21</td>
<td></td>
</tr>
</tbody>
</table>

Visual observation of Table 5 makes it possible to state that budget revenues for 2020 will amount to PLN 2 674 859 million. Their highest level will be in December and it will amount to PLN 416,411,21 million. The lowest one in January 2020 - PLN 40,639.35 million.
For research purposes, Table 6 contains an analysis and evaluation of errors in the forecast made.

Table 6

<table>
<thead>
<tr>
<th>Error</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average percentage error</td>
<td>-0,06</td>
</tr>
<tr>
<td>Average absolute percentage error</td>
<td>1,92</td>
</tr>
</tbody>
</table>

The evaluation of Table 6 is that the average absolute MAPE percentage error is 1.92% and it means that the obtained forecast is good.

4. Conclusions

The goal of the article has been achieved. Forecasting of budget revenues in Poland for 2020 on a monthly basis was performed. Holt-Winter’s exponential smoothing method turned out to be the best method for forecasting.

The forecast for 2020 budget revenues is PLN 2,674,859.00 million. The arithmetic average per month of budget revenues in 2020 is PLN 222 904.92 million. The median is lower and amounts to PLN 219 921.85 million. The lowest month - January is the revenue of PLN 40 639.35 million, and the highest one - December is PLN 416 411.21 million. The lower monthly budget revenue quartile for 2020 in Poland is at PLN 117 553.50 million, and the upper one at PLN 236,074.20 million. The range between the highest and the lowest value is PLN 375 771.86 million. The standard deviation was PLN 124,588.82 million. The distribution of budget revenue forecast is slightly right-hand asymmetrical and more flattened than the normal one.

The information obtained regarding the analysis and evaluation of budget revenue data is extremely important from the point of view of the main macroeconomic problems as they allow to make many planning decisions regarding the expenditure of planned budgetary resources in the aspect of security.

References

The Impact of Motor Oils Quality on Improving the Reliability in Operation of Traction Rolling Stock

Yu. Zelenko¹, M. Bezovska², R. Skvireckas³, L. Neduzha⁴

¹Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St. 2, 49010, Dnipro, Ukraine, E-mail: j.v.zelenko@gmail.com
²Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St. 2, 49010, Dnipro, Ukraine, E-mail: marina84@ua.fm
³Kaunas University of Technology, Studentu st. 56, 51424, Kaunas, Lithuania, E-mail: ramunas.skvireckas@ktu.lt
⁴Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St. 2, 49010, Dnipro, Ukraine, E-mail: nlorhen@i.ua

Abstract

In modern operating conditions of rolling stock, railway safety is one of the priority issues. The safe operation of traction rolling stock is impossible without the effective use of all its components. One of the main characteristics of rolling stock is the reliability, the level of which is associated with the efficiency of its operation. The reliability is closely related to such an important issue as environmental safety in operating a railway vehicle. Domestic and world experience in operating autonomous locomotives indicates that diesel power plants play a decisive role in this. An important part of the diesel engine in a locomotive is the oil system. The annual formation of a significant amount of used oils requires solving the problem of their further safe storage.

The article considers the impact of motor oils quality on the reliability in the operation of traction rolling stock. In this connection, a new method in recovering of used oils of different marks and returning them to the production process is proposed. This will contribute to increasing the safety in operation of railway equipment on the railways, improved economic performance, minimizing the amount of waste and their negative effect on the environment and so on.

KEY WORDS: rolling stock, motor oils, environment

1. Introduction

In modern operating conditions of rolling stock, railway safety is one of the priority issues. The safe operation of traction rolling stock is impossible without the effective use of all its components. In particular, in order to increase this efficiency, appropriate organization and subsequent management of the production process at all stages are necessary.

One of the main characteristics of rolling stock is the reliability, the level of which is associated with the efficiency in its operation. The reliability is ensured through monitoring, inspections, restoration of the technical condition of locomotives and diesel trains. To ensure their reliable operation, there are complexes of measures – from maintenance to repairs of different types of individual rolling stock units and their elements. In order to increase the reliability of traction rolling stock, it is necessary to monitor separately the state of each unit to detect malfunctions at all stages of operation and disposal. As reliability is closely connected with such an important issue as the environmental safety of operating a railway vehicle (for example, carbon pollution Fig. 1), it is necessary to investigate this topic more thoroughly.

2. Developing a New Method for Eliminating Problems Associated with Used Oils

Domestic and world experience in operating autonomous locomotives indicates that diesel power plants play a decisive role in this [1, 2]. An important part of the diesel engine in a locomotive is the oil system. It performs several functions, in particular, maintains the necessary oil pressure to ensure fluid friction in the crankshaft bearings and other friction units, lubricates the cylinder-piston group, provides cooling and heat removal from the pistons of the diesel engine and its other friction units and aggregates, their corrosion protection, removal the wear products from the working surfaces of nodes.

Since diesel engines have significantly more types, designs, methods of mixture formation, purpose, etc., oils for diesel engines have more than 50 varieties of different groups and subgroups [3-6]. During operation, motor oil completely changes its composition and characteristics, because it interacts with the heated parts of the equipment, pollutants, water, etc. The analysis of this information (i.e. physic-chemical analysis of the oil) allows estimating the real status of the diesel engine, to predict its further operation. The method of such estimation is based on the comparison of the values of product concentrations (elements) of wear and contamination of different types with limit values [7, 8].
Important information can also be obtained after the chemical analysis of used oils concerning the content in a number of heavy metals. According to the ecological classification, heavy metals include those that have an atomic weight of more than fifty atomic weight units (a.w.u.) and have pronounced toxic properties indicating their ecological danger. They include lead (207.2 a.w.u.), nickel (58.7 a.w.u.), cuprum (63.5 a.w.u.), zinc (65.4 a.w.u.) and others. [9]. The increase in the amount of these metals in oils indicates the unsatisfactory operation of the diesel engines because after exceeding certain concentrations of metals it can be stated that the diesel engine is in an emergency state and there is a need to carry out repair and technical measures [10].

The annual formation of a significant amount of used oils requires solving the problem of their further safe storage. After analyzing the situation on the domestic railways, it has been established that used motor oils are accumulated at the railway infrastructure enterprises in considerable quantities [11-13]. Most of these wastes are at locomotive service enterprises, which annually produce about 200 tons of used oils. Nowadays, such oils are more often left at railway enterprises and used without regeneration as furnace and boiler fuel, which leads to the loss of this valuable product, or they are transferred for future use (regeneration) to other non-railway enterprises (for example, for lubricating molds at reinforced concrete factories, construction plants, and other needs instead of the corresponding fresh petroleum products). One of the schemes for handling motor oils, which is widely used in the structural divisions of the railway, consists of four blocks (Fig. 2).

Blocks 1–4 of the scheme include the engine oils delivery to the enterprise, incoming quality control, direct use and subsequent application.

Such usage of used oil (collection, storage, cleaning, regeneration and return to the technological process) is attributed to a number of environmental and economic needs. It is a complex multi-level procedure regulated by the relevant legislative acts, orders, and resolutions of state institutions. They approve certain regulations for the used oils collection, which are calculated as a percentage of fresh oil consumption. Subsequently, based on them, they develop
plans for the collection and regeneration of used oils for enterprises in various industries. Enterprises are obligated to strictly observe the requirements for preliminary activities. They include [7, 14, 15]:
- used oils collection of different marks and different levels of contamination in separate tanks with the corresponding marking;
- storing them with the required temperature (using thermal insulation and heating means);
- transportation to regeneration points;
- compliance with the technical specifications for the refined oil products;
- thorough inspection of the serviceability and, in particular, leakproofness of reservoirs (tanks), containers to prevent moisture ingress and foreign objects;
- periodic cleaning of a tank from the sediment formed as a result in the settling of oil.

It is worth noting the danger of bacterial contamination of the oil, which becomes especially relevant after long-term storage of used oils. This situation may be associated with the wear of the additive: this is an additive that is a part of the oil and it improves its properties, but it can no longer fully perform its functions.

Also common is the non-compliance of the formulation in oil preparation, for example, a violation in "the base oil – additive" ratio. This can contribute to the occurrence of such adverse effects as significant emissions of pollutants into the atmosphere during the operation of rolling stock and can become a considerable problem [16, 17].

Consequently, the formation and long-term storage of waste of used oils pose a threat both from the operation of railway vehicles and from an environmental perspective [18-24]. There are a number of methods for restoring the original properties of oils. Every one of them has its advantages and disadvantages [25, 26].

After finding ways in solving these topical issues for railway infrastructure enterprises and research, the group of authors proposes a new method of restoration and regeneration of M-14V and M-14G;TSS motor oils, which are most often used in railway enterprises (namely locomotive depots) in engines of traction rolling stock.

While developing the method of restoring the operational quality of the used motor oils, the results of laboratory research of different cleaning methods and the optimized variant of the selected technology were taken as the basis, namely temperature conditions, a number of reagents, time of their contact with the oil, etc.

As a result, an advanced scheme in handling motor oils is proposed. It consists of five blocks and looks as follows (Fig. 3).

![Fig. 3 The advanced scheme in handling motor oils](image-url)

Blocks 1–3 of this scheme are identical to the same Blocks of the previous scheme. The process of recovery of used oils according to the proposed new method takes place in Block 4, where they are heated, mixed with reagents, centrifuged and mixed with additives to bring all performance indicators to the standards of state regulations and specifications. Therefore, we propose to pump used oils from the crankcase of the locomotive to a special balancing container and after settling to the first-degree mixer, where the oil is heated to the required temperature. Reagents in the desired amount are added from special containers. After mixing, the mass flows through a pipeline to a centrifuge and then to the second-degree mixer.

Further, an additive is added to the same mixer by the dosing pump and the mixing process is ongoing. Subsequently, the finished oil is pumped into a special storage tank or directly into a tank car for light petroleum products. If necessary, you can transport prepared oil to other users by railway or tankers.
This can be done with two options for implementing the proposed technological scheme:
- the first is to obtain small quantities of oil that will gradually accumulate in a special storage tank on the territory of an individual linear division of railways for their internal needs;
- the second is for a substantial amount of recovered oil under the operating conditions of large oil regeneration stations that serve a considerable number of enterprises.

In Block 5 (Fig. 3), the final quality inspection of oils is carried out before their reuse.

In the process of testing the developed method, it is proved that it has several advantages over existing technologies, namely, it provides: a significant cleaning effect (about 90%), the output of the purified product, greater environmental safety [12, 13].

The heavy metals content in fresh, rejected and recovered oils according to the proposed method was also investigated from the view of ecological safety (results are shown in Table).

<table>
<thead>
<tr>
<th>Motor oils of different marks</th>
<th>Heavy metals (gross amount, mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lead</td>
</tr>
<tr>
<td>The content in oil M-14V₂</td>
<td></td>
</tr>
<tr>
<td>fresh</td>
<td>35</td>
</tr>
<tr>
<td>rejected</td>
<td>69</td>
</tr>
<tr>
<td>recovered</td>
<td>12</td>
</tr>
<tr>
<td>The content in oil M-14G₂TSS</td>
<td></td>
</tr>
<tr>
<td>fresh</td>
<td>14</td>
</tr>
<tr>
<td>rejected</td>
<td>17</td>
</tr>
<tr>
<td>recovered</td>
<td>2</td>
</tr>
</tbody>
</table>

The results in Table demonstrate a significant decrease in the amount of these heavy metals after oil treatment and confirm the safety and environmental friendliness of the recovered oils after applying the new method [12, 13].

3. Conclusions

The content of used motor oils includes a number of important data, the analysis of which allows us to predict the further operation of traction rolling stock units. The large number of them when operation creates additional problems and costs for railway enterprises due to the difficulties with their transportation and storage.

The impact of motor oils quality on the reliability of operation of traction rolling stock is considered. In this connection, the new method for the recovery of used oils and returning them to the production process is proposed. This will help to enhance the safety of railway equipment, improve economic indicators, minimize the amount of waste and their negative impact on the environment, etc.

References

Abstract

This article highlights a theoretical quality evaluation method of the rail track + vehicle system performance based on the kinematic characteristics of the vehicle’s body design point and the interaction forces of its wheels with the track rails in transition sections (hereinafter TS) of various shapes. To calculate these characteristics a multifactor deterministic kinematic model (hereinafter MDKM) was proposed. With its help the quality of various known shapes of TS was investigated. The results of such an assessment could be useful in choosing or improving the TS curvatures shapes of ordinary, high-speed and super high-speed railways (hereinafter SHSR).

KEY WORDS: railway transition section, transition curves, cant transition, kinematics of the vehicle body design point

1. Introduction

The previously proposed analysis of TS shapes with singular unit functions \(f(s)\) of the curvature regularities of the transition curve and cant transition \([1-3]\) indicates a clear tendency to increase the degree of \(G^n\) continuity, observed at the starting and terminal points of their conjugation with adjacent graph elements of the corresponding track properties. All curves formed with such regularities take spiral shapes (see Fig. 1).

![Spiral curves with different smoothness degrees of curvature](image)

Fig. 1 Spiral curves with different smoothness degrees of curvature from \(G^0\), to \(G^6\), as described by various \(f(s)\) functions (HSP – half-sine polynomial curves)

To conjugate the straight and curved track sections the initial segments of these spirals with relatively small lengths \(L\) and angles \(\beta\) are used. Usually, this rule is used in the classic style of TS axis tracing at the rail top level (hereinafter RTL). In such case, its current curvature \(k_0(l)\) is calculated in accordance with the curvature degree of the circular part of the curve \(K = 1/R\) also considering current length fraction \(s = l/L\) as in Eq. (1):

\[k_0(l) = K \cdot f(s)\]  

(1)

With an exception of the clothoid the corresponding \(f(s)\) function graphs of the cant \(d(l)\) or the cross slope \(i(l)\) transitions of the track have a so-called half-sine shape. Their current values are also calculated in dependence to the fraction of the current lengths \(s\) also taking into the account the calculated value of the external rail height \(D\) or the maximum cross slope value \(I = D/S\) (where \(S\) – the distance between the axes of the rails) as it is shown in Eqs. (2) and (3):

\[d(l) = D \cdot f(s)\]  

(2)

\[i(l) = I \cdot f(s)\]  

(3)

Practical experience shows that increasing the degree of smoothness reduces the acuteness of the generally recognized quality problems of the vehicle movement at the terminal points of the TS. However, increasing the
smoothness of the function \( f(s) \) reduces of the smooth change of its first derivative \( df/ds \). In this case it results in the growth of a depending on it designed lifting speed of the vehicle external wheel and leads to changes in transverse acceleration at the RTL. Compliance with normative limits at higher degrees of smoothness of the function \( f(s) \) can be achieved only by increasing the TS length.

As the requirements for speed and the comfortable movement grew, the number of proposed new solutions for the functions \( f(s) \) increased for both the classical and the “uplifted” style of rail axis tracing at the level of the vehicle design point, elevated above the RTL by the value of \( H > 0 \) [1-4]. The abundance of such solutions exacerbates the problem of selecting and normalizing the parameters of each one of them. The specificity of transport infrastructure facilities does not allow us to resolve this dilemma by means of trial and error. Therefore, the only acceptable alternative solution is to run a qualitative assessment of railway track + vehicle system performance at railway transition sections of various shapes, based on the results of mathematical modeling of this process.

2. The Argumentation of the Model Type and the Accountable Factors

It is practiced in the process of theoretical studies to implement models in which, as a rule, we use generalized statistical data of motion experimental studies on existing shapes of TS. They cannot be implemented to investigate their new shapes. Therefore, at the current stage of research, a deterministic model was applied. Its analytical regularities provide results that are justified by the aggregate of the factors considered.

Among the factors affecting the performance quality of railway track + vehicle system at TS of selected shape are: velocity of vehicle \( v \), m/s; curvature of the curve in its circular part \( K = 1/R \), m\(^{-1}\); cant (the elevation of the external rail above the internal) \( D \), m; height \( H \) of the vehicle design point above the RTL, m; length of the transition section \( L \), m; function type \( f(s) \) of the cant transition \( d(l) \) and the vehicle inclination slope \( i(l) \); function type \( f_i(s) \) the bend of transition curvature of the track axis \( k_0(l) \); function type \( f_k(s) \) the bend of longitudinal profile curvature of the track axis \( k_V(l) \); symmetric or asymmetric cant transition \( D \); distance between the rail axes \( S \), m.

The complex interaction of these factors and their current values determines the magnitude of the transverse force \( F_C \) which effects the vehicle body, as well as the reaction forces of the left \( F_{L} \) and right \( F_{R} \) rails of the track at each point of the trace \( l \), these forces conditioned to the action of gravitational \( G_L, G_R \) and centrifugal \( C_L, C_R \) accelerations, are determined in accordance with the design scheme presented in Fig. 2.

Fig. 2 Gravity (a) and centrifugal (b) components of accelerations and interaction forces of the railway track + vehicle system elements and summary vectors of rail reaction forces \( F_{L} \) and \( F_{R} \) determined by vector direction of non-compensated lateral acceleration \( a \) and the force \( F_{C} \)

According to these schemes, values of these force vectors which are acting normally on wheel pair axis, are determined as the sum of their gravitational and centrifugal components \( F_{GL} = G_L + C_L \) and \( F_{GR} = G_R + C_R \). They are described by the following equations:

\[
F_{GL} = \frac{m}{2} \left( g_L(l)\cos \alpha(l) - \frac{H}{S} \sin \alpha(l)\left(g_L(l) + g_R(l)\right)\right) + mk_{H}(l)v^2 \left( \frac{1}{2} \sin \alpha(l) + \frac{H}{S} \cos \alpha(l) \right); \\
F_{GR} = \frac{m}{2} \left( g_R(l)\cos \alpha(l) + \frac{H}{S} \sin \alpha(l)\left(g_L(l) + g_R(l)\right)\right) + mk_{H}(l)v^2 \left( \frac{1}{2} \sin \alpha(l) - \frac{H}{S} \cos \alpha(l) \right),
\]

where \( k_H \) – motion trajectory curvature of the vehicle center of gravity, m\(^{-1}\); \( g_L, g_R \) – vertical acceleration, which determines the gravitational component of the interaction force of the left and right vehicle wheel with the railway track.
in current curvature value $k_l(l)$ and $k_R(l)$ of the cant transition chart, m/s$^2$; $\alpha$ – current vehicle angle inclination slope, rad; $v$ – velocity of vehicle, m/s; $m$ – designed load on the vehicle axis, T.

The vertical accelerations $g_L$ and $g_R$ are determined according to $g = 9.81$ m/s$^2$ at current curvature values $k_R(l)$, $k_l(l)$ and $k_R(l)$ according to the formulas:

$$g_L(l) = g + v^2 \left(k_r(l) + k_L(l)\right);$$  
$$g_R(l) = g + v^2 \left(k_r(l) + k_R(l)\right).$$  

Eqs. (4) and (5) allow us to conclude that the vector value of the non-compensated lateral force $F_C$ which act normally on the axis of the vehicle cross section can be expressed as:

$$F_C = m \left(k_H(l) v^2 \cos \alpha(l) - \left[g + v^2 \left(k_r(l) + \frac{1}{2} \left(k_L(l) + k_R(l)\right)\right]\right] \sin \alpha(l).$$

Also, the instantaneous value of reaction forces of the left $F_{L}$ and right $F_{R}$ railway track on the load from the corresponding vehicle wheels at each point of its trace are determined by the formulas:

$$F_L = \sqrt{F_{L_{0}}^2 + \left(F_C \geq 0\right) F_C^2};$$

$$F_R = \sqrt{F_{R_{0}}^2 + \left(F_C < 0\right) F_C^2}.$$  

Dependencies (4-10) allow us to evaluate the vehicle movement quality at maximum values of interaction forces of the railway track + vehicle system, and also its dynamics. It strongly depends on the changing values of the non-compensated lateral acceleration $a(l)$ which acts in the horizontal plane calculated level $H$. According to equation (8), the current values of $a(l)$ at each point of the trace should be calculated taking into account its cross slope $i(l)$ as in the formula:

$$a(l) = k_H(l) v^2 - \left[g + v^2 \left(k_r(l) + \frac{1}{2} \left(k_L(l) + k_R(l)\right)\right]\right] i(l).$$

The change rate of non-compensated lateral acceleration $\psi(l)$ is defined as the derivative $da/dt$ (where $t$ – the motion time, s) according to the formula:

$$\psi(l) = v \left(\frac{dk_H}{dl} v^2 - \left(g \frac{di}{dl} + v^2 \left(k_r(l) + \frac{1}{2} \left(k_L(l) + k_R(l)\right)\right) + i(l) \left(\frac{dk_r}{dl} + \frac{1}{2} \left(\frac{dk_L}{dl} + \frac{dk_R}{dl}\right)\right)\right)\right).$$

The calculating accuracy of the values of these characteristics depends on the calculating accuracy of the curvature $k(l)$ of the vehicle design point motion trajectory at the level of $H > 0$. Therefore, in this model, the curvature is calculated using the coordinate method for describing its kinematics according to design scheme on Fig. 3. In accordance with it, the patterns of the orthogonal coordinates $x_M$ and $y_M$ of the vehicle design point motion trajectory M
As a result, the centrifugal acceleration at the discontinuity points of the track axis at such TS at RTL level.

In this case, the curvature regularity \( k_{\psi} \) of horizontal projection of the design point \( M \) motion trajectory which is located on the vehicle vertical axis at the level \( H > 0 \) is absolutely accurately described by the differential equation:

\[
k_{\psi}(l) = \frac{d^2 x_M}{dl^2} \frac{d^2 y_M}{dl^2} \frac{d^2 x_M}{dl^2} \frac{dy_M}{dl}.
\]

Eqs. (4)-(15) describe as MDKM where the parameters of the designed vehicle interact with geometric properties of various TS shapes traced by classical style at the RTL level. This same model also allows to evaluate the quality of the railway track + vehicle system functioning at TS designed according to “lifted up” style traced at the height \( H_{\psi} \) [3]. In such cases, instead of using Eqs. (13) and (14), we should use the following formulas:

\[
x_M(l) = x_0(l) - (H - H_{\psi}) \cdot i(l) \cdot \sin \beta(l);
\]

\[
y_M(l) = y_0(l) + (H - H_{\psi}) \cdot i(l) \cdot \cos \beta(l).
\]

It’s easy to verify that, when \( H = H_{\psi} \), the motion trajectory coordinates \( x_M \) and \( y_M \) of the vehicle design point \( M \) will correspond to the coordinates \( x_0 \) and \( y_0 \) of the designed curvature functions of the TS axis \( f(s) \) traced at the height \( H_{\psi} \). And if \( H = 0 \) they will correspond to the coordinates \( x_0 \) and \( y_0 \) which describe the so-called out-swinging transition curve [1] of the track axis at such TS at RTL level.

3. The Obtained Results of TS Shape Quality Analysis

This MDKM was applied to analyze large number of known TS shapes with various combinations of initial values of the parameters \( R, D, L, H, V \) and \( S \). In order to exclude the influence of other factors it was considered that they are located on straight sections of longitudinal profile where \( k_{\psi} = 0 \), and their elevation \( D \) was allocated symmetrically.

The worst performance quality of the railway track + vehicle system was shown by clothoid TS shapes with a linear cant transition \( D \). Their disadvantages were manifested in a significant leap in the transverse forces \( F_{C} \) and \( F_R \) values, which lead to the so-called lateral jerk of the vehicle body at the beginning and at the end of the TS curves. The main reason for this negative phenomenon is due to the large curvature \( k_L \) of the elastic bending of the rail in the vertical plane, which is observed at the beginning and at the end of the TS with a linear \( G^0 \) cant transition \( D \). In this case, the curvature \( k_{\psi} \) at the level \( H \) of the vehicle center of gravity (hereinafter CG) can be calculated using the simplified formula \( k_{\psi}(l) \cdot k_{\psi}(l) \cdot k_{\psi}(l) \cdot H/S \). As a result, the centrifugal acceleration \( a \) at the beginning of the TS, due to the curvature \( k_{\psi} \) and speed \( v \), can’t be immediately compensated by the transverse slope of vehicle inclination \( i \). At the end of the TS, it is added to the centripetal acceleration \( i \cdot g \), which should have compensated it.

If we increase the length of clothoid TS it will partially reduce the acuteness of this problem, but it will not eliminate it completely. The combination of the clothoid transition curves and the half-sine functions \( f(s) \) of the cant transition \( D \) various smoothness degree can only mitigate this drawback at the beginning and at the end of the TS. Significant discrepancy in regularity of \( f(s) \) and \( f(s) \) creates the problems almost throughout the entire length of the TS. They lead to the nonlinear change character in the non-compensated lateral acceleration \( a(l) \), as well as in the forces \( F_C, F_L \) and \( F_R \). As a result, the vehicle body suspended on springs will swing. Similar problems are inherent to the \( G^0 \) smooth shape TS described in the standard [1]. Due to their insufficient smoothness the diagram of the non-compensated lateral acceleration \( \psi(l) \), calculated at the vehicle design point level using formula (12), at the beginning and at the end of TS will change intermittently. Also, when we use composite form \( f(s) \) function Helmert (Schramm), we can observe a jump in the diagram \( \psi(l) \) in the middle section of the TS. This defect preserves the probability of lateral jerk at the discontinuity points of the \( \psi(l) \) function. But the main problem of all known half-sine shapes of TS traced at the RTL with similar functions of cant and curvature \( f(s) \) lays in an uneven change of the forces \( F_L \) and \( F_R \) effect, which initiates the vehicle body rocking at sections of its movement with variable curvature and cant.

To handle this defect, many solutions were recently proposed in the form of non-standard polynomials or
trigonometrical functions $f(s)$ which linearize the central part of the cant curvature that they describe [2, 5]. As an analytical example of such TS shapes we can demonstrate and consider one of them, its author refers to it as Order (3,7) and consider it to be the best solution [2]. This opinion could be justified by the fact that the non-standard polynomial function $f(s)$ of Order shape (3,7) with its element’s degrees from 5th to 15th has $G^4$ level of smoothness and provides a linear deviation of cant and curvature on a significantly large portion of the TS central part (see Fig. 4, a).

Fig. 4 Diagrams of values of the function $f(s)$ Order (3,7) for classic (a) and out-swinging transition curves type (b).

Tracing at RTL  
“Lifted up” tracing, $H = 2200$ mm

Fig. 5 Distribution diagrams of vehicle quality movement integrative characteristics on TS when tracing at RTL and at $H = 2200$ mm according to Order shape (3,7)
The function quality of the railway track + vehicle system on the TS of this form was evaluated by using the above-mentioned MDKM with the following initial data: \( R = 8000 \text{ m}, \ D = 150 \text{ mm}, \ V = 400 \text{ km/h}, \) and \( CG = 1800 \text{ mm}. \) These parameters correspond to the SHSR, and the elevation of the vehicle CG was adopted according to EU recommendations [1]. Unfortunately, the description of the Order (3,7) solution does not include more strong evidence of its quality and it also does not include recommendations for the required lengths \( L. \) Therefore, it was assigned equal to TS length \( L = 420 \text{ m}. \) As study results show such TS length can ensure comfortable passenger movement, evaluated for the given parameters \( R, D \) and \( V \) at the design level \( H = 2200 \text{ mm}. \) However, this quality could be ensured only if we complying to the terms of another TS shape harmonization. This method will be described in the next publication.

The Order (3,7) solution, as well as descriptions, of other modern solutions provide their implementation both in the classical style and in the “lifted up” style of tracing proposed by H. Hasslinger [3] (see Fig. 4, b). In these cases, the proposed non-standard half-sine \( f(s) \) functions with a linearized middle section of their diagrams reduce maximal high values of the function \( \psi(l) \) in the middle section of TS, inherent in this method. By the sum of its indexes the \( f(s) \) function Order (3,7) among all other solutions provides the highest level of performance quality of the railway track + vehicle system. This affected our choice to use it as an example to analyze the inherent disadvantages of these solutions.

Analyzing these diagrams, one can conclude that linearization of the central part of the \( f(s) \) function graph even with a high smoothness degree \( G^4 \) does not eliminate the causes that lead to vehicle rocking (see Fig. 5). This is indicated by the uneven change pattern in the reaction forces of the track rail \( F_L \) and \( F_B. \) Also, with the classical tracing of TS at the RTL according to Order shape (3,7) significant oscillations amplitudes of the function \( \psi(l) \) are inherent, which will adversely affect the comfort of passengers’ movement.

The “lifted up” tracing module ensures an almost perfect character of the diagrams \( a(l) \) and \( \phi(l) \) at designed level \( H, \) which is critical for passenger comfort. However, this does not apply to the diagrams characteristics of accelerations and forces acting at the CG level of the vehicle body and at the levels of the local CG of other vehicle structure elements. Due to the inherent to these levels amplitudes of alternating oscillations of \( a(l) \) function, the uniformity of changes and the direction of the interaction forces of the elements of railway track + vehicle system is violated. As the difference between the design critical level of comfort \( H \) and the levels of application of forces to the vehicle massive elements grow, the disturbance of this uniformity will increase. Also, we can add to the disadvantages of such solution the complexity of the track construction and maintaining it in proper condition the geometry of the outswinging transition curves with a non-monotonous alternating change of curvature \( k_d(l). \)

4. Conclusions

The results of the deterministic multivariable analysis using the described model Eqs (4)-(17) are consistent with the real problems of the rail track at TS on the railway curvatures that are practically recognized or may arise if one or another new shape of TS would be implemented. The proposed model also helps in identifying the causes of these problems. The analysis of causes can help to find the most acceptable solution from all known TS shapes and to improve new shapes of TS that can ensure an increasing demand and more strict requirements of travel quality by means of railway transport on the sections with variable curvature and inclination of the vehicle body. One such solution obtained by this methodology will be described in the next publication.

References

1. EN 13803-1:2010: Railway applications -Track-Track alignment design parameters - Track gauges 1435 mm and wider - Part 1: Plain line [Required by Directive 2008/57/EC]
Obstacles and Benefits of Real Time Information Exchange Between the Ferry and Shipping Users

L. Filina-Dawidowicz1, V. Paulauskas2

1West Pomeranian University of Technology, Ave. Piastów 41, 71-065, Szczecin, Poland, E-mail: ludmila.filina@zut.edu.pl
2Klaipeda Shipping Research Centre, Klaipeda university, V. Berbomo str. 7-5, LT-92219, Klaipeda, Lithuania, E-mail: vytautasklci@gmail.com

Abstract

Continuously growing requirements for transport services affect the changes in multimodal transport chain operation. One of them is the need for real time information exchange between the participants of transport chains, especially those using ferry connections. The article aims to present the obstacles to implementing real time information exchange, as well as the range of possible benefits that may be achieved by ferry shipping users. On the basis of literature analysis and interviews with stakeholders who use and offer ferry connections in the Baltic Sea region, it was possible to identify the scope of obstacles and benefits related to real time information flow and divide them into groups perceived from different perspectives.

KEY WORDS: multimodal transport, real time data, ferry shipping, obstacles, benefits.

1. Introduction

In regard to the European Union (EU) transport policy, which promotes maritime transport as an alternative to road or rail ones, the dynamic increase is observed in traffic within the multimodal transport chains. Multimodal transport allows using the advantages of the particular transport modes to carry the transport processes efficiently and make its customers satisfied.

The increase in ferry traffic in the EU, including in the Baltic Sea region, is an effect of changes in the multimodal transport chain operation. These changes are influenced by international trade development and the growing volume of cargo flow, EU transport policy implementation, the processes of internationalization and globalization, etc. The changes are also connected with the increasing requirements of transport companies’ customers [19]. The owners of cargo want to receive consignments on time, without damages and at low costs and determined time. They also want to be well informed about the performance of the particular stages of transport processes. The same situation is observed in behavior of passengers who want to be sure about the transport vehicles’ schedule, including arrival and departure times.

Ferry shipping is the specific and at the same time significant maritime sector that assures the extension of road and railway transport, by carrying passengers, cars, trucks, busses, and, in some cases, railway wagons within permanent services between designated ports. Due to the specific conditions of ferries operation the delays or cancelations may occur as an effect of unfavorable weather conditions, technical and technological problems and others. That may influence the waiting time increase, unacceptable by ferry lines customers [6], who would like to receive real time data to adjust to the unexpected changes. Unfortunately, the ways of informing the users of any changes to the schedule of ferries are not satisfactory. Often, this information is passed to the stakeholders too late, e.g. when the user is already in the ferry terminal. For that reason, new approaches should be implemented in transport services to make the customers satisfied. That is why it is important to ensure real time data availability for the particular participants of multimodal transport chains.

One of the ways to improve the real time data flow is to develop and introduce IT solutions. Such solutions are based on the application of toolsets available for the different users and adjusted to their requirements. On the one hand, the implementation of these solutions in practice deals with the number of obstacles. On the other hand, real time information flow should provide the benefits that will be significant for the particular participants of multimodal transport chains and will encourage and convince them to use this data.

The conducted literature analysis revealed that there is a number of research articles that analyze the ways of registration and transfer of real time data in maritime and land transport [1, 2, 8, 11, 15, 18]. There are also positions related to ferry shipping operation [5, 7, 8, 10,12, 14, 16] and transport activity benefits [3, 4, 20]. However, there is a lack of available literature complexly describing the types and scope of obstacles and benefits that may be achieved by ferry shipping stakeholders utilizing the ferry real time data. That was the motivation of undertaking the research that aims to identify the range of possible obstacles to implement real time information exchange and benefits that may be achieved by real time data users of multimodal transport chains on the ferry shipping example.

2. The Users of Real Time Data in Ferry Shipping

Ferry transport is a specific type of regular shipping between ports located at relatively small distances. Ferry
shipping is an important sphere of socio-economic activity. It plays a significant role in goods transport, trade, tourism and leisure, as well as the profitability of interested stakeholders. Ferry shipping is characterized above all by [13]:

- traffic regularity on routes with different lengths;
- usage of specialized ships - ferries, that allow quick reloading of a roller, self-propelled loads, as well as provide passengers service;
- usage of specialized ferry terminals, enabling efficient service of passengers and cargoes;
- transport of cargo and passengers on the basis of a valid passenger ticket or according to a specific transport tariff etc.

In the Baltic Sea region, ferry shipping is of great importance, creating a common and single market for both cargo and passenger transport, which illustrates the thriving activity of many carriers trying to meet the growing traffic demand. Ferry lines usually set the schedule as the basis for ferries traffic. The real time data also come from ferry lines and when the differences between it and the scheduled data are identified, it should be transferred to the interested actors.

There are different stakeholders interested to receive real time data (Fig. 1). Mainly, passengers and drivers are travelling by ferries. However, the forwarders and transport companies (public and cargo) are interested in real time data, that will allow them to plan the routes more efficiently using one or several transport modes. These data are also needed for ports, including ferry terminals that have to plan the cargo service and ship activity, as well as inform their customers about any changes in ferries schedules. Logistic companies are interested to have the data on their cargo delivery. Moreover, some actors (e.g. cargo transport companies, forwarders) need these data to inform their customers (e.g. cargo owners) about the stage of transport process performance. It should be also highlighted that the ferry real time data will be useful for travel planners and satellite navigation data providers that can implement it in their services.

The analysis of the scope of data necessary for the users of multimodal transport chains performed with the participation of ferry shipping showed that the real times of ferry departures and arrivals are the most valuable for them. Such information is of great interest to all stakeholders who are willing to utilize ferry real-time at lower costs and less effort as a result. The visualization of ferry information for travelers and transport companies may be conducted through mobile applications, screens at ferry terminals in ports or on roads, etc.

3. Methodology

To collect the data on possible obstacles and benefits related to the implementation of real time information exchange, the selected literature positions presented in available databases were reviewed. On the basis of literature analysis it was stated that no complex elaborations were presenting the obstacles, as well as benefits for ferry shipping users, however it allowed to understand better the scope of analyzed problem.

The interviews with stakeholders who perform and use ferry connections in the Baltic Sea region were held during Real Time Ferries project (RTF) partners meeting in Rostock (Germany) in June 2019. During this meeting
among other issues the expectations and possible benefits of real time information flow were discussed with the representatives of shipping lines, ports, transport companies, IT developers, researchers and other partners, who use ferry lines as passengers (35 people in total). The stakeholders were from such countries as: Sweden, Germany, Poland, Lithuania, Latvia, Estonia, Finland. Each person could share the opinion answering the question: “What will be the benefits of ferry real time data utilization?”. The obstacles were discussed individually. Implementing the system approach to the obtained data it was possible to identify the scope of possible obstacles and benefits, as well as divide them into specific groups.

It should be highlighted that after identification the particular benefits and obstacles may be analyzed in more detail. For that purpose the individual evaluation methods may be adjusted. One of the possible evaluation methods deals with assessing the intensity of the occurrence of selected obstacles group considering that particular problems (obstacles) within the group are stochastic processes. This intensity \( E \) may be calculated as follows:

\[
E = \frac{1}{P'},
\]

(1)

where \( P' \) - the probability of obstacles group occurrence, which can be calculated using the formula:

\[
P' = (1 - Q_1)(1 - Q_2)...(1 - Q_n),
\]

(2)

where \( Q_1, Q_2, \ldots, Q_n \) - the probability of occurrence of particular \( i \) problem within the obstacle’s group, \( i = 1, 2, \ldots, n \).

The implementation of this approach will give the possibility to assess particular groups of obstacles. The same theoretical methods could be used for the evaluation of the benefits.

4. Results

Based on the collected data, the groups of obstacles related to the real time data exchange in multimodal transport chains were elaborated (Table 1). These obstacles were mainly related to financial, technical and technological, as well as organisational aspects. The main identified problem was the necessity to possess the financial resources for platform development and its further maintenance that required i.a. developing of the business model in line with market needs. Moreover, the problems with IT solutions implementation and insufficient integration of actors generating and using these data were also considered. These obstacles may limit and delay the development of the platform and obtaining benefits by participants.

<table>
<thead>
<tr>
<th>The groups of obstacles</th>
<th>Selected examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td>Limited financial resources for implementing IT solutions and platform maintenance, etc.</td>
</tr>
<tr>
<td>Technical and technological</td>
<td>The need to set technical specifications of a platform and individual IT applications, as well as the data standards; possible disruption in ensuring integration, the connection of the applications to the platform and smooth data transfer, etc.</td>
</tr>
<tr>
<td>Organizational</td>
<td>Challenges with ensuring the cooperation of a large number of participants, including ferry lines, ports, transport companies; limited willingness to connect the platform and sharing the data observed in some enterprises, etc.</td>
</tr>
<tr>
<td>Social</td>
<td>Possible problems with enabling the use of developed solutions for different groups of users, including the elderly and disabled, etc.</td>
</tr>
<tr>
<td>Administrative</td>
<td>The need to change set procedures in the company; disruptions in obtaining permission to implement changes on a larger scale etc.</td>
</tr>
</tbody>
</table>

The preliminary results of the conducted research on the possible benefits of the real time information utilization by actors of multimodal transport chains are shown in Tables 2, 3 and 4. It was possible to identify the groups of benefits that may be perceived from different perspectives (Table 2).

<table>
<thead>
<tr>
<th>The groups of benefits</th>
<th>Selected examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical</td>
<td>Cost savings for individual participants, as well as the entire transport chain, etc.</td>
</tr>
<tr>
<td>Ecological</td>
<td>CO2 emission reduction, less fuel consumption and traffic jams decrease, etc.</td>
</tr>
<tr>
<td>Technical and technological</td>
<td>Usage of innovative technical solutions and tools for data transmission, etc.</td>
</tr>
<tr>
<td>Organizational</td>
<td>Time savings, performing the increased number of operations per time unit, better cooperation between partners, data transmission improvement, better punctuality and predictability, better utilization of equipment, staff etc.</td>
</tr>
<tr>
<td>Social</td>
<td>Less stress of transport services users, better usage of time during the trip, etc.</td>
</tr>
<tr>
<td>Administrative</td>
<td>Simplified information flow procedures, etc.</td>
</tr>
</tbody>
</table>

Table 1

Table 2
The main benefit essential for all stakeholders is improved information flow giving the possibility to particular actors to be informed better about the travel opportunities and cargo state. It should be highlighted that the benefits will be different considering the user groups (Table 3). They are also related to ferry lines that through providing real-time data to become more competitive on the market.

Table 3

<table>
<thead>
<tr>
<th>The groups of users</th>
<th>Possible benefits examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passengers (by foot, car or bus)</td>
<td>Less stress while waiting for the ferry etc.</td>
</tr>
<tr>
<td>Drivers (lorries, trucks, buses etc.)</td>
<td>Waiting for time reduction in port etc.</td>
</tr>
<tr>
<td>Cargo transport companies (road, rail)</td>
<td>More elasticity in planning the route and drivers resting time, costs reduction etc.</td>
</tr>
<tr>
<td>Public transport companies, taxies</td>
<td>Better adjustment to the changes in ferry schedules, better planning of route and drivers resting time, costs reduction etc.</td>
</tr>
<tr>
<td>Forwarders</td>
<td>Less manual work, the better possibility to plan and execute the route to deliver the cargo on time, costs reduction etc.</td>
</tr>
<tr>
<td>Travel agencies</td>
<td>Better informed clients etc.</td>
</tr>
<tr>
<td>Ports (authorities, ferry terminals etc.)</td>
<td>Reduction of overtime of staff, better image etc.</td>
</tr>
<tr>
<td>Logistic companies</td>
<td>Possession of actual information about the consignment status etc.</td>
</tr>
</tbody>
</table>

Moreover, the benefits may have different size and scope (Table 4). They may deal with individual interests, as well as have a global range.

Table 4

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Types of benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>The entity using the transport services</td>
<td>Individual benefits – related to the particular user, e.g. passenger, Collective benefits – related to the stakeholder’s group, e.g. group of drivers or taxi companies.</td>
</tr>
<tr>
<td>Operating range</td>
<td>National benefits – connected with the interest of particular country participating in multimodal transport using ferry shipping, a better image of the country on the international market, International benefits – related to the joint interest of participants from different countries directed to improve cross-border transport services.</td>
</tr>
<tr>
<td>The way to use the benefit</td>
<td>Direct benefits – related to the data users, e.g. shortening of waiting time of drivers in port, Indirect benefits – connected with the transport companies’ customers and whole market benefits, influencing the competitiveness growth and sustainable development of the whole ferry transport market.</td>
</tr>
</tbody>
</table>

In order to assess the particular groups of benefits and obstacles the approach shown in Methodology Section may be applied. The case study of the exemplary port was considered and the group of technical and technological obstacles that may influence the real time information flow was analysed. Within the obstacles’ group, the probabilities of particular problems appeareance may be determined: $Q_1$ - probability of delay in development of IT application for data transfer; $Q_2$ - probability of disruption in ensuring connection of the application to platform; $Q_3$ - probability of improper application operation; $Q_4$ - probability of difficulties while installing application on the computer/smartphone; $Q_5$ - probability of disruption in data transfer from ferry line to the platform.

Assuming that the probabilities of particular problems occurrence are as follows ($Q_1 = 0.03; Q_2 = 0.05; Q_3 = 0.15; Q_4 = 0.05; Q_5 = 0.25$), it is possible to calculate the probability of group of technical and technological obstacles’ occurrence using formula (2):

$$ P' = (1 - 0.03)(1 - 0.05)(1 - 0.15)(1 - 0.05)(1 - 0.25) = 0.56 . $$

Thus, having found the probability of a group of obstacles’ occurrence, we can calculate the total intensity of this group occurrence according to formula (1):

$$ E = \frac{1}{0.56} = 1.79 . $$

To sum up, the scope and range of possible benefits is rather wide and tends to the growth of efficiency of transport services, as well as customers satisfaction increase. Utilization of ferry real time globally will give the wide-scale benefits covering the different aspects of human socio-economic activity sphere.
5. Conclusions

One of the current ways to improve multimodal transport services is the development of technics and tools to share the real time data between the participants of transport chains. It mostly refers to the ferry shipping sector, where the real time data on ferries arrivals and departures should be available to all interested stakeholders and allow them to get their benefits. Moreover, these data should be visible on travel planners, including Google Maps etc.

For this purpose, the IT-architecture for real time data transfer should be developed. Its implementation can enable the increase of customer satisfaction, the growth of the number of ferry shipping users, as well as will provide the benefits contributing to the sustainable development of transport.

It should be highlighted that there is a number of obstacles in real time data flow that prevents possible benefits achievement. They are dealing mainly with financial restrictions, insufficient integration of actors generating and using these data, as well as problems both with data flow processes organisation and technical solutions implementation that also need financial outlays. Particular benefits and obstacles may be assessed using the presented approach. That will allow us to support the decision making process when implementing real-time data exchange tools.

Future research will cover a more detailed analysis on the benefits related to particular solutions implementation achieved by specific groups of stakeholders of multimodal transport chains, including those using the ferry shipping.

Acknowledgements

This paper is based on the research conducted within the Interreg Baltic Sea Region project Real Time Ferries (RTF).

References

Rapid Prototyping Used in the Automotive Rubber Parts Production

D. Barta¹, V. Pavelčík², J. Caban³,⁴

¹University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia, E-mail: dalibor.barta@fstroj.uniza.sk
²University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia, E-mail: vladimir.pavelcik@fstroj.uniza.sk
³University of Life Sciences in Lublin, 28 Głęboka Street, 20-612 Lublin, Poland, E-mail: jacek.caban@up.lublin.pl
⁴Lublin University of Technology, Faculty of Mechanical Engineering, Nadbystrzycka 36, 20-618 Lublin, Poland, E-mail: j.caban@pollub.pl

Abstract

The article deals with problems of construction of an injection molding rubber prototype mold for the production of automobile cuffs. It mentions general knowledge of materials that are mostly used for the production of flexible elements, and present three possible ways of improvement of prototype mold parts for rubber elements, which are based on the 3D printing technology.

The aim of the work was to confirm the possibility of using rapid prototyping technologies in the design and production of vulcanization molds, to verify the mechanical properties of prototype products, to test the possibility of production of prototype products and to verify prototype life.

KEY WORDS: rubber, injection mold, rapid prototyping, 3D print, epoxy resin

1. Introduction

In the modern world, rubber is an irreplaceable part of our lives. The properties that rubber has (elasticity, plasticity) predetermine it for use in all areas of industry. Gardynski and Lonkwic [2] studied the physical and chemical properties of polymer materials used in passenger lifts. Polymer materials help reduce the weight of vehicles, which brings benefits in the form of lower fuel consumption and gas emissions to the atmosphere [10]. The development of technologies in the automotive industry is largely based on various rubber compounds. Whether it is various damping elements, seals, bushings, wiper blades, carpets, insulation, tires and other components, these components are often not even perceived by car users or they do not attach as much importance to them as they actually have. Rubber products are made of rubber compounds, whether natural or synthetic. Today, natural rubbers are still widely used because synthetic rubbers cannot match the properties of natural rubbers. Rubber parts are formed by the vulcanizing of rubbers in molds. Preparing to produce each rubber product, with respect to the manufacturing process, is quite expensive, especially due to the high cost of the mold, and also time consuming [16]. Therefore, the effort is to use new technologies in the production of molds. Molds don’t always need to be machined out of metal, but they can be 3D printed. Layer additive technologies are of interest to many parts of manufacturing industries [13]. As Rankin et al [9] noted the progress of 3D printing improves with each generation of this technology. They are more and more widely used in manufacturing centers specializing in prototypes and designs [12]. The modeling device – 3D printer usually uses materials such as plastic, wax, metal or gypsum. These materials are usually extruded onto a base surface where they cure. 3D printing uses different processes for producing various components. Such processes are for example Fused deposition modeling (FDM), Selective laser sintering (SLS), Direct metal laser sintering (DMLS), Electron beam melting (EBM), Inkjethead 3D printing, Laminated object manufacturing (LOM), Stereolithography (SLA), Polyjet Matrix, Material Jetting (MJ), Multi Jet Modeling (MJM), Binder Jetting (BJ), or Digital Light Processing (DLP). However, not all processes and not all materials meet the requirements for injection molds for rubber processing. The correct selection of material depends on the type of 3D printing technology as well as it is directly associated with the requirements of the mold itself[14].

According to [15] the stereolithography (SLA) 3D printing provides a cost-effective alternative to machining aluminum molds. SLA parts are fully solid and isotropic to withstand the pressure of low-volume injection molding. For low-volume production (approximately 10-100 parts), 3D printed injection molds can save money and time compared to expensive metal molds. They also enable a more agile manufacturing approach, allowing engineers and designers to prototype injection molds and test mold configurations or to easily modify molds and continue to iterate on their designs with low lead times and cost.

2. Materials Used for the Production of Flexible Elements

Among engineering materials, plastics are among the youngest construction materials [7, 11]. In general, the material used for the production of flexible elements is called rubber. Fundamentally, rubbers are elastomers – macromolecular substances. Their chemical compound can differ, depending on the type of elastomers. There are many types of rubbers used in engineering, some of them are mentioned below.
Natural rubber is being extracted from latex – milky suspension, which is collected from the rubber tree via the tapping process. Most natural-rubbers-substances have good strength before vulcanization, high vulcanization speed and final products are abrasion-resistant, elastic and rigid. They have good dynamic features and are therefore used in tires, springs and silent blocks.

Rubber can also be prepared synthetically. The world’s most widely used synthetic rubber is a copolymer of butadiene and styrene – styrene-butadiene rubber (SBR). Two monomers are mixed and then polymerized either from solution (S-SBR) or as an emulsion (E-SBR). E-SBR is produced either at lower or at a higher temperatures, whereas the lower-temperature E-SBR is better from the dynamical and mechanical points of view. S-SBR has a more complicated production process but has a positive impact on adhesion between tires and road, abrasion resistance and heating during service [6].

Butadiene rubber (BR) consists of polybutadiene and has a higher oxidation-resistance rate compared to other diene rubbers. BR has lower toughness, strength, but higher elasticity and abrasion resistance. Most of the world’s production is used for tire treads.

Special rubbers having at least one special feature, e.g. resistance to oil, high temperatures, aging, etc. are produced for special purposes. In the automotive industry, for silent-blocks, hoses, etc., oil – resistant rubbers are used to improve the lifetime of the machines. Another important group of rubbers is the silicon rubbers. Thanks to its content, it is non-reactive and resistant to temperatures from -60°C up to 180°C in normal service in a dry environment. Its purpose of use in the automotive industry is mainly for thermally stressed components [3].

The production of new polymers is getting harder and more expensive [1]. Hereby it is important to state, that many types of rubber remained unmentioned above, but it is not the purpose of this article to mention them all.

3. Prototype Molds Part Improvement

Rubber parts are formed by vulcanizing rubbers in molds. For vulcanization process, the following three types of molding are used: compression, transfer/extrusion and injection molding [16]. Injection molding is the dominant method of processing polymer materials, due to the complexity of the structures of the obtained moldings (variations in shape, dimensions and mass) and the range of types of plastics that can be used [5]. In our tests, the injection molding method was used. The injection molding process is presented in Fig. 1. The rubber is heated to become softer and then is injected into the mold. Rubbers used for this method must meet the highest criteria – resistance to beginning the vulcanization process and very good flow features. No preparation of any rubber semi-finished product is needed, which increases the production efficiency.

![Fig. 1 The principle of injecting the mixture into the vulcanization mold](image)

3.1. Prototyping a Vulcanization Mold Using 3D Printing

Prototypes of vulcanization molds are most commonly made of metals. However, the need to make the production more effective and to decrease the cost of prototype mold leads to the usage of modern technologies and non-metal materials.

Mold material selection is very important, because it must withstand all the physical effects during the vulcanization process, for example, temperatures up to 180°C and pressure 120 bar. These requirements were met only by epoxy resins designated especially for the production of vulcanization molds. No other epoxy resin was able to withstand the given temperature. In most cases, the material softens at higher temperatures (temperatures above 80°C).

The prototype mold for our purposes consisted of three parts. All these mold parts were printed on a Projet 660 Pro 3D printer from silicon powder. Since the first tests showed that the 3D prints were not able to withstand the high pressures and temperatures that occur during the vulcanization of rubber, it was necessary to propose their subsequent treatment. As a final solution, two modifications were selected, and subjected to physical and practical tests.

3.2. The First Modification

The first modification was done by strengthening of the mold by absorbing other material. The strengthening material absorbed by this form was the epoxy resin infusion type Raku-tool EC-2401, which is directly intended for vulcanization molds for the rubber industry. The epoxide was mixed with the epoxy hardener EH-2974 in a weight ratio
of 100:10. Due to the insufficient ability of this resin to soak into the printout, another type of resin was subsequently used, namely type EL-2204 / EH-2954 in the mix ratio 100:40. The ability of the resin to be absorbed into the silicon mold depends on the viscosity of the resin. For optimal hardening of the resin, the mold was heated on the temperature 180°C and left there for 14 hours. Then, slow cool down to normal temperature 20°C was performed. The mold modified in this way was placed in the mother frames and inserted into a REP M36 vulcanizing injection molding machine, by means of which a rubber cuff prototype was created.

After applying the release agent specifically designated for vulcanization molds, the mold was filled with the material – rubber mixture based on natural rubber FSIN 4090 SK, with parameters: hardness 40 ± 5 Shore A, density 0.99 g.cm⁻³, tensile strength at break 26 MPa and elongation at break 600%. Due to too low pressure of 50 bar, as well as a temperature of 106°C, the first attempt failed. Very bad heat conductivity of silicon powder was the main reason of the failure, although steel cylinders were implemented to improve this feature of the mold – the interior of the mold remained too cold to start the vulcanization process.

![Fig. 2 3D print of a vulcanization mold soaked in epoxy resin (left) and cracked after the test (right)](image)

For the second attempt, the mold’s temperature was increased to 130°C, and the time of the process was extended to 30 min. Increased temperature successfully vulcanized the mixture, however, the epoxy resin hardness decreased. With this modification, three rubber cuffs were vulcanized, but all of them with significant errors (Fig. 3). No more pieces could have been made because of the prototype mold deformation (Fig. 2). Even though this solution seemed to be satisfactory, the results of testing denied this hypothesis [10].

![Fig. 3 Damage to the middle part of the vulcanization mold](image)

### 3.3. The Second Modification

The second modification principle lies in the creation of whole vulcanization mold from epoxy resin. To make it, negative molds needed to be made from polyurethane, using 3D prints of the vulcanization mold as a master model. Silicon molds could not have been used due to its missing resistance to amine released during the reaction of epoxy resin and hardener. Polyurethane PM 1045 / DM 5223 with a Shore hardness of 45 was used to form the mold. The mixing ratio was 1: 1 by weight.

The polyurethane mold needs enough thickness in order to remain shape-steady and deformation-resistant.
Before pouring the polyurethane into molds, where 3D prints were placed, the vacuum chamber was used to get rid of air bubbles. Polyurethane degassing was carried out at a pressure of 3 mbar for 10 minutes in a vacuum chamber. The polyurethane molds were allowed to solidify for 24 hours at a constant temperature of 20°C and a relative humidity of 60%. A release agent was used where needed. After the polyurethane molds were cleaned of the remnants of the prints and stabilized after the next two days, the holes for air extraction during casting were made (Fig. 4). The same epoxy resin as in the first modification Raku-tool EC-2401 / EH-2974 was injected under pressure outside of the vacuum chamber to create the final epoxy molds. Fully filled molds were heated continuously to 75°C, on which they have been left for one day. Final hardening of epoxy resin was made at 150°C for 14 hours and then cooled down to normal temperature.

For testing of this modification of mold, the same rubber type was used as in the first modification. The temperature of the mounted molds in the mother frames, after total heating, reached 136°C in the whole volume. The first attempt was successful, the vulcanization process succeeded, and no defects of mold appeared in comparison to the first modification with molds soaked in epoxy resin.

For the second attempt, the pressure increased to 120 bar and temperature to 120°C, and a few defects appeared, which is normal at the process of prototyping. However, after the next attempt, one-third of the mold broke. This is considered to be the product of the prototype production inaccuracies. To eliminate the inequalities in compressive forces, the minimal tolerances are required. To sum this modification up, this is nowadays the best way to use modern technologies for creation of vulcanization mold.

Fig. 4 Polyurethane mold during cleaning from 3D printout (left) and prepared polyurethane mold (right)

For testing of this modification of mold, the same rubber type was used as in the first modification. The temperature of the mounted molds in the mother frames, after total heating, reached 136°C in the whole volume. The first attempt was successful, the vulcanization process succeeded, and no defects of mold appeared in comparison to the first modification with molds soaked in epoxy resin.

For the second attempt, the pressure increased to 120 bar and temperature to 120°C, and a few defects appeared, which is normal at the process of prototyping. However, after the next attempt, one-third of the mold broke. This is considered to be the product of the prototype production inaccuracies. To eliminate the inequalities in compressive forces, the minimal tolerances are required. To sum this modification up, this is nowadays the best way to use modern technologies for creation of vulcanization mold.

Fig. 5 Damage to vulcanization molds caused by large geometric tolerances (left) and rubber parts vulcanized in prototype epoxy mold (right)

4. Conclusion

The possibility of achieving the assumed performance parameters of the production process planned for the implementation depends on the degree of reliability of machines and technological devices included in the designed system [4]. Therefore, refining the printing technology is crucial for the quality of the final product obtained. The tests performed have shown that the rapid prototyping technology with using 3D printing is a possible alternative to the classic production of injection molds. In terms of usability and functionality, the second modification is better than the first modification. As it turned out, the use of an injection mold made by 3D printing from resin-impregnated silicon powder is not a suitable solution. However, the second variant with the use of a pure resin injection mold, produced using a polyurethane mold, already has a possible application after eliminating the shortcomings in the inaccuracy of
production. From an economic point of view, the first modification achieved half the cost of production compared to the second one, which is a satisfactory but not sufficient criterion, whereas the main emphasis is on the functionality and practical use of the prototype form. With regard to the experience gained from the two solutions, their advantages and disadvantages, a proposal for a third solution emerged.

The third possible modification consisting of negative mold printed by 3D printer, into which an epoxy resin would be cast to form a positive mold. This way, the process would need no polyurethane form, which makes the process cheaper and faster by at least 24 hours.

Some problems may occur. For example, the epoxy resin could be absorbed by the negative form, making it impossible to separate the molds. Another disadvantage is the surface of the product of 3D printing, which is very porous and very rough and epoxy resin can copy the connected surface. The ideal surface of 3D print would have parameters of the polished surface, which also contributes to a better flow of rubber mixture when injecting. The advantages of this type of mold creation are the possibility of inserting steel mold inlet channels into the negative form, which gives an advantage when high pressures impact on small surfaces. Another advantage is the heat conductivity of epoxy resin, which makes steel cylinders mentioned in the first modification unnecessary.

The parameters of functionality, usability and economic production are also met with a certain assumption by this modification, while the production costs reach approximately the same level as in the first modification. This is due to the use of a 3D printout as a negative form. Therefore, the third solution could be the most suitable for the production of prototype vulcanization molds, but it needs to be tested.

Acknowledgement

The article was created under the support of the grant project KEGA 011ŽU-4/2020 Implementation of online education in the field of bearing technology with an emphasis on the educational process for improving the skills and flexibility of engineering technology students.

References

Flight Inspection with Unmanned Aircraft

A. Novák¹, A. Novák Sedlačková², B. Kandera³, T. Lusiak⁴

¹University of Zilina, Univerzitná 8215/1, 01026, Žilina, Slovakia, E-mail: Andrej.Novak@fpedas.uniza.sk
²University of Zilina, Univerzitná 8215/1,01026, Žilina, Slovakia, E-mail: Alena.Sedlackova@fpedas.uniza.sk
³University of Zilina, Univerzitná 8215/1, 01026, Žilina, Slovakia, E-mail: Branislav.Kandera@fpedas.uniza.sk
⁴Lublin University of Technology, Nadbystrzycka 38 D,20-618, Lublin, Poland, E-mail: tlusiak@pollub.pl

Abstract

Flight inspection of aeronautical ground equipment is an important process and has a direct impact on maintaining air transport safety. Its task is to verify and evaluate the integrity, efficiency of flight procedures, functionality and selected parameters of communication, navigation and surveillance equipment. Traditional flight inspection procedures of aeronautical ground equipment are performed by means of special monitoring flights with a calibration aircraft. This article proposes a procedure for flight inspection of aeronautical ground equipment using Unmanned Aerial Vehicle (UAV), and at the same time compares the advantages and disadvantages of such a verification method based on the practical experience of the authors with such experiments.

KEY WORDS: UAV, remote sensing, flight calibration

1. Introduction

The number of UAVs sold worldwide is constantly growing. Their development and use are becoming increasingly important for various areas of the economy. UAVs have become very common, and their use is diverse. They are used in the army, police, rescue services, remote sensing (imaging, lidar), agriculture, research, transport and logistics, but also as toys for children. Due to their increasingly frequent use, they are constantly evolving, and the relevant legislation needs to be amended. In order to maintain the safety of their operation, there is an increasing need for their detection, tracking and monitoring [1, 8].

The use of UAVs for flight inspection is not a new idea, the first experiments were carried out in Spain (2013-2015), Switzerland (2015-2018), Germany (2016) when the first projects using UAVs for flight measurement of aeronautical ground equipment were carried out.

2. Flight Inspection

Communication, navigation and surveillance devices are the core elements in today's aviation that form the necessary link between the aircraft deck and the Earth. They enable the safe operation of flights on established routes and the provision of the necessary air navigation services. Some aeronautical ground devices are strategically located on the earth's surface (VOR / DME, NDB, ILS, MLS, MKR, PAPI), others in space (GPS, GLONAS, Galileo), but always at a relatively large distance from the aircraft that needs to use radio or visual signals emitted by them. How do we make sure that the aircraft is able to receive these signals and follow them safely? This question has plagued scientists, technicians and pilots since time immemorial. In accordance with ICAO Annex 10 and Doc 8071, it is clear that regular inspections and measurements of specified parameters are performed at each aeronautical ground facility. If these measurements are made on or near the equipment and the results are within the prescribed tolerances, it can be assumed that the signal emitted by this equipment will meet the prescribed requirements at the location of the expected occurrence of the aircraft. In addition, the signal of several devices is formed into the final form only at distances that are outside the range of ground measurement and control technology [2, 4]. Ideally, the signal of the aeronautical ground equipment should be checked at the location of the aircraft just before use, which is impossible. However, it is possible to measure signals directly in the area in which they are expected to be used by aircraft. This will or will not confirm the presumption that the aeronautical ground equipment is operating correctly. Measurement of radio and visual signals parameters of aeronautical ground equipment by a specially modified aircraft or UAV is referred to as flight inspection. The time intervals specified for flight inspection depend on the type of equipment. We can divide them into the following categories:

a) The basic flight inspection of aeronautical ground equipment shall be performed in cases of putting the equipment into usable operation and increasing the category of the equipment, e.g. ILS cat. I to ILS cat. II.

b) Special flight inspection shall be performed at the request of the operator of the installation, usually after an aeronautical emergency, in case of occurrence of three reports of malfunction, after a part of aeronautical ground equipment is hit by a lightning strike, after replacement or repair of the transmitting or receiving antenna (s) or antenna system, after a monitoring system modification, after any activity as a result of which a change in the flight-verified parameter has occurred or may have occurred that could affect the equipment's usability classification.

c) Scheduled flight inspection (SFI) shall be performed on the basis of flexible periodicity by a system of regular flight measurements. In the flexible periodicity system, three types of time intervals between successive regular
flight measurements are used.

2.1. Validity of Flight Inspection

The flight inspection is considered performed on the day when the last monitored parameter was verified. This also applies if the flight inspection evaluation is performed later. The aeronautical ground equipment or flight procedure is applicable to air operations until the date specified in the flight inspection protocol. This date is determined by the system defined above [1]. The flight calibration inspector is entitled to limit the validity of the flight inspection protocol in a justified case. A scheduled flight inspection may be performed thirty days before the expiry of the previously scheduled flight inspection or basic flight inspection. Aeronautical ground equipment may be used in air traffic for a further period of thirty days after the expiry of the scheduled or basic flight inspection, after which the equipment for which the flight inspection has expired has the highest priority for its execution (see Table 1).

<table>
<thead>
<tr>
<th>Aeronautical ground equipment</th>
<th>Basic interval in days</th>
<th>Shortened interval in days</th>
<th>Extended interval in days</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILS</td>
<td>120</td>
<td>90</td>
<td>180</td>
</tr>
<tr>
<td>ILS DME, MKR, PAR, VOR/DME</td>
<td>120</td>
<td>90</td>
<td>180</td>
</tr>
<tr>
<td>SSR/TAR</td>
<td>180</td>
<td>120</td>
<td>365</td>
</tr>
<tr>
<td>COM FIS/ACC/APP/TWR, VHF ATIS/VOLMET</td>
<td>180</td>
<td>120</td>
<td>365</td>
</tr>
<tr>
<td>PAPI, RLS</td>
<td>120</td>
<td>90</td>
<td>180</td>
</tr>
</tbody>
</table>

Interestingly, the frequency of flight inspection varies from country to country, for example [10] for China states the frequency of NDB 270/240 days, DVOR/DME track 540/1080 days, for the terminal area of 270/540 days respectively. These measurement periods are significantly different from the usual standards in Europe and the USA. It can therefore be said that each country sets them differently and they are not fully harmonized by ICAO [3].

3. UAV Flight Inspection

Equipment for flight inspection by means of UAVs must be divided into several categories based on the division of UAVs by European legislation. This subdivision is based on the maximum take-off mass of the equipment (MTOW) up to 150 kg, which is regulated by national legislation, or equipment above 150 kg MTOW, where the conditions are regulated by EASA in accordance with EP and Council Regulation (EC) no. 216/2008 of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency and repealing Council Directive 91/670/EEC; Directive (EC) no. 1592/2002 and Directive 2004/36/EC as amended. In the Slovak Republic, an unmanned aerial vehicle (hereinafter also UAV) means an aircraft capable of flying without a pilot on board (§7 of the Aviation Act). Unmanned aircraft are divided into:

- autonomous aircraft (i.e. unmanned aircraft that do not allow the pilot to intervene in flight control);
- remotely piloted aircraft (i.e. unmanned aircraft operated from the station of the person operating such an aircraft and such station is not on board the remotely piloted aircraft);
- aircraft models (i.e. an unmanned aircraft used for commercial purposes only for sports, competition or recreational purposes).

In all cases, the obligation to operate the aircraft in accordance with the conditions and requirements valid for the use of airspace is applied in the airspace of the Slovak Republic and thorough separation of aircraft capable of flying without a pilot (regardless of their weight) from piloted aircraft is required!

3.1. FIS System Definition

The flight verification system must consist of several parts, a UAV, a ground control and monitoring unit, a reference station and a communication system (see Fig. 1).
Normally, flight inspection uses an aircraft that records the signal in space. On board the aircraft there is a FIS (Flight Inspection System) console, which provides an evaluation of the signal in space [5,6,9]. During the flight inspection, we should be able to calibrate the ground equipment and set its parameters in accordance with the requirements for the specific type of equipment and its installation location and at the same time meeting national legislation and ICAO Annex 10 and DOC 8071. On board the aircraft the flight crew is able to perform all necessary operations during the flight to generate a full flight inspection report, usually performed by the FIS console software depending on local specifications but in accordance with ICAO DOC 8071 [3].

3.2. On-board Equipment for UAVs with FIS

FIS on-board equipment of the UAV must contain an antenna system, 2 GNSS signal receivers for precise positioning and navigation of the device, spectrum analyser, VOR / DME / NDB / ILS / GBAS navigation signal receiver, on-board computer and data modem for communication with the ground control unit. In the case of aircraft, all these devices represent weight in the range of 30 - 55 kg in the case of standard aircraft installation, depending on the number of devices and their redundancy (see Fig. 2). Despite manufacturers' efforts to miniaturize and reduce equipment weight, a few years ago some reputable companies (Aerodata, Rhode & Schwartz, Honeywell) were not able to install the FIS system on small aircraft with an MTOW of up to 2,000 kg. Currently, there are measuring devices on the market that can be installed on UAVs in the MTOW weight category of up to 20 kg, but their use is limited only to a certain type of measurement, e.g. lighting system, ILS, etc. At the same time, the use of a high payload shortens the maximum flight time, which in the case of battery-powered UAVs means that the flight time is reduced to 15-30 minutes.

![Fig. 2 On-board part of the FIS system for UAVs [10]](image)

The system built in this way has several advantages, foremost is compatibility with the existing system in conventional aircraft equipped with a FIS console, while using commonly available receivers, e.g. R&S EVSF1000 spectrum analyser, which is capable of recording and analysing the signal of VOR, ILS, MKR and other devices in accordance with ICAO regulation DOC8071. The dimensions of the device are 95x177x360mm, weight without battery and antenna is 3.7 kg. For the analysis of a DME/SSR/TCAS device, an active device is needed that will be able to generate a query signal and thus simulate an on-board transceiver. Such a device is the R&S SMA100A or the R&S EVS300 device, which can analyse the ILS/VOR/DME and GBAS signal. The dimensions of the device are 342x157x266mm with a weight of 7.3 kg without battery and antenna system. The advantage of these devices is their input voltage in the range of 14-34V and therefore their ability to be supplied from the aircraft's on-board power supply network. Due to the requirement of operational coverage of the device 3000 m (10,000 FT) vertically and 45 km (25 NM) horizontally, it is necessary to use a satellite communication system such as Iridium NEXT for a safe two-way connection. Iridium NEXT uses Iridium 9522B modems with dimensions of 162 × 81 × 28 mm and a weight of 420 g without battery and antenna. To position the antenna and determine the tilt, it is necessary to install an AHRS system, such as VN-100SMD with dimensions of 36 × 33 × 9 mm and weight of 15 g whose task is to provide information for the autopilot, and at the same time to provide information about the position of the antenna in space for the FIS system. The VN-100 is the only sensor in its class to offer a quaternion based, drift compensated Kalman filter operating with full 32-bit floating point precision at update rates as high as 400 Hz. Unlike other commonly used algorithms, a quaternion-based solution ensures reliable operation without the traditional problems associated with gimbal-lock.

3.3. Ground Control and Monitoring Unit for UAVs with FIS

The ground control and monitoring unit perform several functions, its primary function is the control of the UAV flight mode, remote control, communication. The second task is to ensure data transmission and subsequent evaluation of measured data in real time. The on-board computer of the FIS console must transmit the processed data to the ground control unit via a data modem. In the meantime, the operator evaluates the flight and issues instructions to the operator
of the ground equipment to make the necessary modifications to the ground equipment. These changes are usually required when installing equipment or when the technical parameters of the device are changed (replacement of boards, antennas, etc.). It can also include a reference station for georeferencing, usually consisting of RTK GNSS systems. However, this system can also be shared through the network of georeferenced stations of the corresponding country. Example of such a network in the Slovak Republic is SmartNet and SKPOS. The last module is a voice-voice, data-data communication system which ensures a two-way connection between the UAV and the ground control and monitoring unit.

4. The Design Proposal of UAV with FIS

In the above-mentioned case, we have presented the structural arrangement of the system, which is structurally based on existing equipment used for aircraft. In the case of UAVs such a designed system has one major disadvantage, which is the total weight of the system installed on board the UAV. The high weight significantly reduces the range and operating effect of the device or forces the manufacturer to choose a fixed wing instead of a rotor UAV, or to use an internal combustion engine [7].

Let's look at the possibility of building a FIS console for UAV as a "thin client" when we minimize UAV on-board equipment. We propose to use a multi-channel SDR receiver and transmitter, such as LimeSDR Mini, Ettus Research USRR 312, Great Scott Gadgets HackRF One, Nuand bladeRF 2.0 micro, which allow to receive and transmit any signals. At the same time, they enable signal processing in the basic position. It should also include a computer system with an interface supporting GNSS-SDR, with the operating system GNU/Linux, macOS/MacOS X, MS Windows (only through a virtual machine). Communication system, which consists of a VHF/UHF modem in the licensed frequency band or from an LTE modem connected to a mobile operator. AHRS system, which also supports the INS function without the need to connect to a time source from GNSS. Standalone GNSS receiver which supports GPS, GLONASS, GALILEO, BEIDU, ENOS, WAAS. The interface bus is designed as Ethernet 100/1000 Mbps, USB 2.0 or USB 3.0 between the SDR receiver and the on-board computer (see Fig. 3).

From the operation of such a solution point of view there are two possibilities, the first being an autonomous flight, where the UAV is programmed for the whole calibration flight into the autopilot system similarly as it is
Flight inspection of aeronautical ground equipment is a complex process as defined by ICAO Regulation DOC 8071, but national legislation as well as national recommendations may vary significantly. It is worth mentioning that the process of flight verification for individual devices is different in each country, its settings are based on national customs. The introduction of UAV technology into this process could significantly reduce the cost of inspection of aeronautical ground equipment, with the cost of such inspection ranging from EUR 2,500 to EUR 5,500 per flight hour and can often climb to as high as EUR 10,000. These costs represent a relatively large burden, especially for small regional airports operating such infrastructure (e.g. approach light system, PAPI, etc.). At the same time, there is a problem with the planning of such flights, as FIS providers are currently commercial entities, unlike in the past, when this service was provided by the CAA. These changes introduced competition in the market but also created a problem with the availability of the service and its price. The solution would be to allow the use of UAV flight inspection systems. In such a case, the price of measurement could fall to EUR 500 per flight hour. We assume that the development of UAV technology will in the upcoming 10 years enable flight inspection of aeronautical ground equipment using UAV also in autonomous mode during full operation of the airport, or without the need to close sectors and flight inspection locations. The development of new technologies is a clear indicator of such a trend. Our proposed inspection scheme will be used in the academic field to test these possibilities. Given the experience at UNIZA in performing this activity by aircraft, we can perform a comparative measurement of whether the feasibility of the technical design of the FIS UAV would be verified in real operation.

Acknowledgment

This paper is published as one of the scientific outputs of the project: „New technologies and best practices in education in the Air Transport and Professional Pilots”, KEGA 011ŽU-4/2018.

References

3. ICAO DOC 8071 MANUAL ON TESTING OF RADIO NAVIGATION AIDS

Intelligent Transport Systems – for Reduction and Removal of Black Spots

A. Jarašuniene¹, N. Batarliene²

¹Vilnius Gediminas Technical University Plytinės 27, Vilnius, LT-10105, Lithuania, E-mail: aldonas.jarasuniene@vgtu.lt
²Vilnius Gediminas Technical University Plytinės 27, Vilnius, LT-10105, Lithuania, E-mail: nijole.batarliene@vgtu.lt

Abstract

The Intelligent Transport System (ITS) works with information and control technologies providing the core of ITS functions. ITS services can make transport safer and more secure. Traffic safety on the roads of national significance in Lithuania is one of the most important priorities. Efforts are being made to reduce the number of road accident victims. In order to properly evaluate the impact of Intelligent Transport Systems on traffic safety, the article presents a comprehensive statistical analysis on black spots, the financial losses on Lithuanian economy caused by traffic accidents, also accident rate in Europe and the world, ITS applications on Lithuanian roads, measures to minimize accident levels by deploying Intelligent transport systems.

KEY WORDS: black spots, traffic, safety, ITS, accident

1. Introduction

Intelligent Transportation System (ITS) applies advanced technologies of electronics, communications, computers, control and detecting in all kinds of transportation system in order to improve safety, efficiency and traffic situation through transmitting real-time information [1]. The purpose of ITS is to collect information about traffic flows and conditions on roads and to present the obtained data for control systems [2].

Intelligent transportation systems (ITS) are advanced applications that aim to provide new services relating to all modes of transport and traffic management and enable various users to be better informed and make safer [3].

ITS plays an important role in transport applications such as traffic light cameras, electronic tolls, ramp meters, traffic light coordination and passenger information systems [4]. ITS can improve traffic safety, reduce traffic congestion, to improve transportation efficiency, also to reduce air pollution [5].

Black spot is a road segment in which the density of accidents and accident rates have reached or exceeded the limit values.

2011 March 2 The Ministry of Transport and Communication has approved a new national road safety program that would implement the vision of safe traffic and ensure that road users in Lithuania die as little as possible or suffer serious injuries [6].

The purpose of the article is to estimate traffic safety problems in roads of Lithuania, to show the black spots in Lithuania roads, to expound accident rates in Europe and the world, to identify main problems of safety that could be solved by the ways with using intelligent transport systems.

2. Investigation of Black Spots Situation on the Roads of Lithuania

The black spot is a 500 m road segment in which at least 4 traffic accidents have occurred in four years, and the accident density and accident rate have reached or exceeded the limit values.

In scientific literature accidents are classified into different types. The most often the following ones are presented:

- Running down of the vehicle on the pedestrian;
- Crash of vehicles;
- Flipping of the vehicle;
- Running down of the vehicle on the obstacle;
- Falling of passengers.

Most often accidents occur due to that the Road Traffic Regulations are violated by drivers, pedestrians, passengers, bikers, also due to flagrant violations of technical exploitation regulations by transport sector employees, bad state of roads and road traffic organisation control, often due to the fault of animals.

Figure 1 shows a dynamic of the number of black spots on highways, country roads and regional roads in 2009-2018.

An important reason for the accident rate is the lack of moral responsibility. Therefore, for ensuring traffic safety and solving problems it is necessary to apply complex measures designed for fostering the culture of traffic participants and developing skills [7].
3. Financial Losses on Lithuanian Economy Caused by Traffic Accidents

The Republic of Lithuania endures economic losses pertaining to traffic accidents annually. The losses of traffic accidents directly depend on the number of fatalities and injured road users. The average financial loss of the recorded traffic accident to the state is calculated on the basis of certain rates and methodologies. The extent of the state loss is changing depending on the level of the country’s economy and inflation.

Damage to the Lithuanian Economy due to Road Accidents that Occurred on State Roads in 2016–2019 is showed in Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Traffic accidents</th>
<th>Killed</th>
<th>Injured</th>
<th>Damage, million €</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>Traffic accidents</td>
<td>263</td>
<td>43</td>
<td>348</td>
</tr>
<tr>
<td></td>
<td>Killed</td>
<td>43</td>
<td>44</td>
<td>561</td>
</tr>
<tr>
<td></td>
<td>Injured</td>
<td>348</td>
<td>44</td>
<td>561</td>
</tr>
<tr>
<td></td>
<td>Damage, million €</td>
<td>46.49</td>
<td>59.16</td>
<td>1296</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Traffic accidents</th>
<th>Killed</th>
<th>Injured</th>
<th>Damage, million €</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>Traffic accidents</td>
<td>266</td>
<td>48</td>
<td>324</td>
</tr>
<tr>
<td></td>
<td>Killed</td>
<td>48</td>
<td>59</td>
<td>607</td>
</tr>
<tr>
<td></td>
<td>Injured</td>
<td>324</td>
<td>607</td>
<td>1313</td>
</tr>
<tr>
<td></td>
<td>Damage, million €</td>
<td>39.61</td>
<td>54.94</td>
<td>1313</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Traffic accidents</th>
<th>Killed</th>
<th>Injured</th>
<th>Damage, million €</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>Traffic accidents</td>
<td>292</td>
<td>35</td>
<td>398</td>
</tr>
<tr>
<td></td>
<td>Killed</td>
<td>35</td>
<td>47</td>
<td>657</td>
</tr>
<tr>
<td></td>
<td>Injured</td>
<td>398</td>
<td>44</td>
<td>1500</td>
</tr>
<tr>
<td></td>
<td>Damage, million €</td>
<td>36.52</td>
<td>54.74</td>
<td>1500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Traffic accidents</th>
<th>Killed</th>
<th>Injured</th>
<th>Damage, million €</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>Traffic accidents</td>
<td>333</td>
<td>39</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>Killed</td>
<td>39</td>
<td>46</td>
<td>739</td>
</tr>
<tr>
<td></td>
<td>Injured</td>
<td>440</td>
<td>739</td>
<td>1696</td>
</tr>
<tr>
<td></td>
<td>Damage, million €</td>
<td>44.11</td>
<td>62.24</td>
<td>1696</td>
</tr>
</tbody>
</table>

Based on Table 1 data indicate that the state of safety is not good and it requires solutions. The reasons for this are insufficient attention to the improvement of traffic safety and the funds are allocated by the Municipality and the Republic of Lithuania Motor Third Party Liability Insurance Company. Urban and District Safety Traffic Commissions usually work formally with improving the current state of affairs.

More attention should be paid to the traffic culture of road users in the country [8]. Drivers and pedestrians feel respect not only for each other, but also very often violate the Road Traffic Rules. Poor culture and discipline of road users, disregard of road traffic regulations, non-participation of the public in solving traffic safety problems increase the accident rate in the country.
4. Accident Rate in Europe and the World

According to data from the European Commission CARE database an average of 49 people was killed per 1 million inhabitants in the European Union (Table 2).

<table>
<thead>
<tr>
<th>Country</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Sweden</td>
<td>27</td>
<td>27</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>2  United Kingdom</td>
<td>29</td>
<td>28</td>
<td>27</td>
<td>58</td>
</tr>
<tr>
<td>3  The Netherlands</td>
<td>28</td>
<td>31</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>4  Denmark</td>
<td>31</td>
<td>37</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>5  Ireland</td>
<td>36</td>
<td>39</td>
<td>33</td>
<td>31</td>
</tr>
<tr>
<td>6  Estonia</td>
<td>51</td>
<td>54</td>
<td>36</td>
<td>51</td>
</tr>
<tr>
<td>7  Germany</td>
<td>43</td>
<td>39</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>8  Finland</td>
<td>49</td>
<td>47</td>
<td>39</td>
<td>43</td>
</tr>
<tr>
<td>9  Spain</td>
<td>36</td>
<td>39</td>
<td>40</td>
<td>39</td>
</tr>
<tr>
<td>10 Malta</td>
<td>26</td>
<td>51</td>
<td>43</td>
<td>38</td>
</tr>
<tr>
<td>11 Austria</td>
<td>56</td>
<td>50</td>
<td>47</td>
<td>45</td>
</tr>
<tr>
<td>12 Luxembourg</td>
<td>64</td>
<td>56</td>
<td>47</td>
<td>60</td>
</tr>
<tr>
<td>13 Slovenia</td>
<td>58</td>
<td>63</td>
<td>50</td>
<td>44</td>
</tr>
<tr>
<td>14 France</td>
<td>54</td>
<td>54</td>
<td>53</td>
<td>48</td>
</tr>
<tr>
<td>15 Czech Republic</td>
<td>70</td>
<td>58</td>
<td>54</td>
<td>62</td>
</tr>
<tr>
<td>16 Belgium</td>
<td>67</td>
<td>56</td>
<td>55</td>
<td>52</td>
</tr>
<tr>
<td>17 Italy</td>
<td>56</td>
<td>54</td>
<td>56</td>
<td>55</td>
</tr>
<tr>
<td>18 Slovakia</td>
<td>57</td>
<td>51</td>
<td>57</td>
<td>46</td>
</tr>
<tr>
<td>19 Cyprus</td>
<td>67</td>
<td>54</td>
<td>62</td>
<td>57</td>
</tr>
<tr>
<td>20 Portugal</td>
<td>57</td>
<td>54</td>
<td>62</td>
<td>59</td>
</tr>
<tr>
<td>21 Hungary</td>
<td>65</td>
<td>62</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>22 Lithuania</td>
<td>84</td>
<td>66</td>
<td>67</td>
<td>61</td>
</tr>
</tbody>
</table>

In Lithuania 2018 61 per 1 million people died. A higher number of deaths per million inhabitants than in Lithuania in 2018 were in such European countries like – Czech Republic (62 killed per million inhabitants), Hungary (64 killed per million inhabitants) [9]. The highest position among European Union countries in 2018 had Sweden. In Sweden, there were 25 deaths per 1 million inhabitants [9].

Analyzing the distribution of fatalities by road maintenance institutions in 2018, were killed 67% of all road users in roads maintained by the Lithuanian Road Administration (LAKD), and 33% of all road deaths on Lithuanian roads were killed by road sections supervised by municipalities. Compared to 2011, when the strategic goal was set, the number of people killed by road accidents in road sections maintained by LAKD decreased by 45%, on municipal roads and streets – by 29%.

5. Intelligent Transport Systems for Reduction or Removal of Black Spots

The Intelligent transportation system (ITS) is the application of control, sensing and communications technologies to ground transportation in order to improve safety [10].

Through a variety of road safety solutions, the modern world seeks to reduce the number of accidents and ensure safe mobility. ITS operates as systems based on a well-developed network of weather and traffic monitoring equipment, various driver information and information centers [11].

Driver distraction is a leading factor in car crashes. With a goal to reduce traffic accidents and improve transportation safety, it is important to propose a driver distraction detection system that identifies various types of distractions through a camera observing the driver [5].

**Driver Attention Monitoring System.** Studies have shown that about 20% of accidents occur due to driver fatigue. Long-distance driving and resting while sitting behind the wheel promote sleep. To address this, driver attention monitoring systems have been developed. When the equipment detects a driver's drowsiness, the system immediately warns with audible signals and vibration. The driver attention monitoring system is constantly being improved and updated [12, 13].

**Horizontal road marking** – horizontal marking lines glow in the dark with photo luminescent powder. It charges during the daylight and glows about 10 hours in the dark. Similar technology can be used to light-up bicycle lanes with illuminated stones. When the negative temperature reaches the road surface, snowflakes painted with dynamic paint warns road users about the slippery road surface [14].
LED lighting system – Cat Eye alters the horizontal marking and it is an intelligent, LED lightening system that uses renewable energy resources. The system can be used in dangerous sections instead of noise bands, it can warn about changing driving conditions (side-lines before the horizontal curve shines with green colour, in the curve itself it shines with red colour and behind the curve it shines with white colour), it may be installed in dangerous curves. The vehicle that has reached it activates the system that gradually lights up in the direction of the curve. The system can be used to warn drivers about pedestrians passing through or approaching [8, 15].

The AEB system improves traffic safety in two ways: firstly, when the sensors detect a potentially dangerous situation, the driver is alerted by video and audio signals [16]. Vehicle manufacturers are introducing different AEB systems: Audi calls such a system “Pre-Sense, Mercedes-Benz – Pre-Safe, Toyota – Pre-Collision, but their operation is similar. The system is programmed to be able to respond to situations where vehicles in the front are moving in the same direction as the vehicles with the installed system. The two modes of visual processing enable us to determine pedestrians intending to cross vehicle driving trajectory. A high-resolution camera can even detect the type of pedestrian movement.

Cooperative Intelligent Transport Systems. Cooperative Intelligent Transport Systems (hereinafter, C–ITS) provide real-time communication between vehicles, road infrastructure and road users. Vehicles and road elements operating in the system have ITS station with a standardized structure consisting of communications and technical equipment. Maintaining continuous wireless communication among three groups enables to ensure traffic safety, the efficiency of traffic control and a positive impact on the environment. The system, which serves road users and managers, facilitates their actions [17].

The term cooperative means wireless communication between personal devices and vehicles (P2V); vehicle to vehicle (V2V); a vehicle to road infrastructure (V2I); road infrastructure to personal devices (I2P). The most important communication in this system is the one established between vehicle to vehicle and vehicle to transport infrastructure, however, there is a possibility to communicate with pedestrians or cyclists with personal communication devices. It is very likely, that deployment of V2V system into new vehicles should increase from 10.9% in 2018 and 69% in 2027.

The secure system operation requires a communication signal that is reliable, free of charge and low waiting times. The key tool used to support such a communication signal is the Dedicated Short-Range Communications (hereinafter, DSRC).

 Blind Zone Monitoring System. This device can capture vehicles passing through electromagnetic waves or digital cameras for real-time monitoring and analysis. If the driver turns and one of these devices detects another vehicle in a blind spot, an audible and visual warning of the possible danger is sent to the driver. In dangerous situations, the advanced systems do not even allow you to turn the steering wheel at all. The blind zone monitoring system is constantly being improved and updated [18].

eCall system. It is a car system that aims to significantly reduce the number of serious accidents [19]. EU law requires all new cars to be equipped with GPS-enabled automatic eCall technology. This technology can speed up emergency calls and thus reduce the number of fatal accidents. In the event of an emergency, the system automatically sends the data to the emergency number 112 [20].

Following the acceptance of EU requirements and the introduction of many different ITS tools, the number of fatalities in Lithuania has significantly decreased.

6. Conclusions

1. By implementing EU requirements, Lithuania seeks to ensure safe transportation and reduce the number of traffic accidents by various means. The country has published a National Road Safety Policy, which sets out the directions to be taken in implementing road safety solutions.

2. It is necessary to analyze the distribution of fatalities according to certain Lithuanian roads - highways, country and regional roads. The safety of all road users is a top priority.

3. With the help of various road safety solutions (driver attention tracking system, horizontal road marking, LED lighting system, the AEB system, eCall system etc.) Lithuania aims to ensure safe transportation and achieve a reduction in the number of traffic accidents.

4. The highest efficiency of ITS would be achieved if a unified system connecting all modes of transport, multimodal transport infrastructure and traffic control is established.

References


5. Tran, D.; Do, H.M.; Sheng, W.; Bai, H.; Chowdhary, G. 2018. Real time detection of distracted driving based on
deep learning, IET Intelligent transport systems, 12(10, 12).


The Modelling of Post Office Time Availability by Isochrones

R. Madleňák¹, D. Hoštáková², M. Dobroselskyi³

¹University of Zilina, Univerzitna 8215/1, 01026, Zilina, Slovakia, E-mail: radovan.madlenak@fpedas.uniza.sk
²University of Zilina, Univerzitna 8215/1, 01026, Zilina, Slovakia, E-mail: dominika.hostakova@fpedas.uniza.sk
³University of Zilina, Univerzitna 8215/1, 01026, Zilina, Slovakia, E-mail: mykhailo.dobroselskyi@fpedas.uniza.sk

Abstract

The paper deals with the issue of time availability of postal facilities in a selected settlement. Based on the analysis of the requirements for the availability of access points of the public postal network, a mapping of the availability and demand of postal services in a selected city in Slovakia is carried out. Using the isochrone techniques, the modelling and subsequent optimization of the number and location of access points of the public postal network in the territory of the selected city will be carried out.

In the conclusions, the proposed solution will be evaluated to reduce the costs related to the operation of post offices located in the city territory and concerning the set requirements for the quality of the universal postal service.

KEY WORDS: postal network modelling, optimization of access points of postal network, isochrones, time availability

1. Introduction

The term availability is one of the most defined terms in the geographical literature, for which there are various methodological approaches. Commonly, availability can be defined as the ease of reaching a certain place from other places using the transport system [1].

The essential elements that are related to availability include the subject of accessibility, the object of availability and the transport element. The subject of availability represents a person, a group of persons or inhabitants of a certain territory, that is located in a certain place (the starting point), and from its point of view, the given availability is examined. The availability object represents a predetermined goal (a certain opportunity, activity, service), the availability of which is determined. Since the place of departure and the place of the set (achieved) goal are usually spatially separated, it is necessary to overcome the distance between them [2]. It is ensured using a transport element comprising the specific transport system in which the transport takes place, as well as the variable distance defined in the transport system [3].

As each element of availability can be understood in different ways, the importance of knowing the individual elements of availability lies primarily in their connection to the measurement of availability. It is because the indicators by which availability is quantified are derived from these elements [4].

The diversity of approaches in the availability study is also reflected in the number of measures used, which are classified by different authors into different groups. For example, Tolmaci [5] distinguishes five categories of availability measures (metrics):

- Metrics that indicate the existence and possibilities of links (and the number of these links) and also their various quantitative or qualitative characteristics (the number of stops, simple distances that defining the diameter of the graph and others).
- Cumulative availability metrics are expressing the "position" of the selected facility (node) relative to others. It is determined by the sum of the quantitative characteristics, which can be expressed by time, by the distance between facilities (kilometers) or by cost (money).
- Metrics based on the gravitational relation (gravity model), which are characterized by the "weights" of the facilities (nodes).
- Availability in which the theory of accidental utility is applied. Quantitatively, it determines the probability of individuals choosing a certain goal to the relative probability of other possible choices.
- Measures that express the relative spatial arrangement of a defined region.

All of these availability measures have in common distance between the point of departure and the destination of the journey. The distance can be divided into objective and subjective. Objective distance is a distance that can be clearly expressed or measured, such as physical distance (km), time distance (hours, minutes) or economic distance (expressed in financial means) [6, 7].

The subjectively defined distance is the so-called cognitive distance that the individual derives from the transformed mental image of the world that he gradually creates in his mind. Often cited examples include estimating the distance between the center and the periphery from the perspective of residents living in both places. Close to such an understanding is an affective and social distance, which indicate the perceived degree of separation.

Availability rates can also be divided into quantitative and qualitative. Quantitative measures of availability are usually expressed in terms of time, distance in kilometers or cost of money between the individual phenomena studied.
Qualitative measures of availability are characterized by the characteristics of a certain area, such as the occurrence of bus stops in the vicinity of the investigated phenomenon, occurrence of administrative facilities, shopping centers and others. These qualitative availability measures often influence the spatial availability perceived by customers, based on which they then decide to choose a specific company or operation to meet their needs [8].

The availability of the postal service is an essential requirement for the universal postal service, which is prescribed by EP Directive no. 97/67/EC, Acts of the Universal Postal Union and Act no. 324/2011 Coll. on Postal Services and Amendments to Later Acts. EP Directive no. 97/67/EC defines the universal postal service as a service available on working days to everyone under the same conditions throughout the country, in the same quality and at an affordable price [9]. Where the availability of the universal postal service is ensured within the national territory by the national provider through the access and contact points of the public postal network [10].

Modelling is one of the most general ways of displaying real situations using an assembled model [11]. According to Chovanec [12], the term modelling means the process of creating a model and verifying its correctness, truthfulness and accuracy for the investigated system. The essence of modelling is the replacement of the investigated system by its model or system that models it. The aim of modelling is using experiments, the so-called experiments with the model to obtain information about the original investigated system. The process of experimentation in which the properties of a model are examined is called simulation [13, 14].

The model is thus an idealized imitation of a part of the real world. By combining the principles of model construction and mathematical assemblies, it describes statistically how some parts of a certain system react to changes in other parts of that system [15]. The model is only a selective approximation, which, by excluding random and irrelevant details, makes it possible to emphasize some basic, essential or exciting aspects of the real world, which is thus displayed in a certain generalized form [16].

Based on the earlier definitions, the modelling of the postal network can be characterized as a simplified and structured way of displaying the existing postal network for its research and optimization [17]. When modelling the postal network, it is crucial to take into account the basic conditions determining:

- the number and location of delivery and delivery points depending on the settlement structure and its demographic and geographical functions, such as transport or location of public service facilities, as well as its logistical functions representing vehicle use or the number of network connections;
- number, location, technical and technological parameters of processing centers based on the logistics functions of the postal system [18, 19].

2. Objective and Methodology

Modelling the availability of the postal network can be characterized as a representation of the real situation of the existing postal system and its equipment ensuring the availability of postal services through a compiled model for its investigation or optimization. This article aims to model the availability of postal facilities (post offices) in the postal network via isochrones.

Several steps precede the process of creating a model. The first step is to map the current state of availability of post offices located in the selected area. Furthermore, given that the density of the postal network should take into account the needs of users, the second step must identify the requirements of the postal undertaking's customers for the spatial availability of post offices. The third step is to determine a suitable method for compiling a model of the availability of the postal transmission network. In our case, it will be the construction of a model using isochrones. For these reasons we used software QGIS 3.12 with plugin ORS Tools. QGIS is a user-friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public License. ORS Tools plugin provides access to most of the functions of openrouteservice.org, based on OpenStreetMap. The tool set includes routing, isochrones and matrix calculations, either interactive in the map canvas or from point files within the processing framework. Extensive attributes are set for output files, incl. duration, length and start/end locations.

The implementation of the calculation was applied to the territory of a particular city – Zilina. The city of Zilina is the fourth largest city in the Slovak Republic, with a population of 82 730 (April 2020). The city of Zilina is divided into 24 city districts, namely Banova, Borik, Brodno, Budatin, Bytca, Celulozka, Hajik, Hliny, Mala Praha, Mojsova Lucka, Chimec, Priemyselná zona, Rosinky, Solinky, Stare Mesto, Strazov, Trnovec, Vlacince, Vranie, Zabreh, Zahradie, Zavodie, Zilinska Lehota and Nova Zilina. Directly in the city of Zilina, there are currently 11 active post offices. Three post offices only accept postal shipments (Post office Zilina 2, Post office Zilina 5, Post office Zilina 10) and eight post offices that accept and deliver the postal shipments (Post office Zilina 1, Post office Zilina 3, Post office Zilina 4, Post office Zilina 7, Post office Zilina 8, Post office Zilina 9, Post office Zilina 14, Post office Zilina 15). At present, 11 postal facilities are capable of meeting customer requirements. Their locations are presented in the Fig. 1.

Through the performed analysis, we came to a conclusion where the individual postal operations are located (where are the locations of post offices). However, we cannot determine whether the post office is or is not within the required distance of the customer. Therefore, to fulfill the main objective of the article, questionnaire research was carried out aimed to determine the maximal time which the customers of Slovenská pošta, a.s. are willing to dedicate to travel for the postal services provided at the post offices. For this reason, a research goal was set: to find out what is the time distance that the customers of Slovenská pošta, a.s. are willing to travel for the postal services offered at the post offices.
3. The Results and Discussion

A total of 390 respondents with a predominance of female representation took part in the questionnaire survey. In terms of age, the most numerous group consisted of respondents aged 26 to 35 years and the least respondents were aged 66 and over. Of the total number of respondents, about the same number were respondents from the urban area as respondents from the rural area. Specifically, 53% of respondents stated that they come from the metropolitan area of Zilina city and 47% of respondents from the rural areas of the regional districts of Žilina or Bytča.

Since our research aimed to analyze the time availability of post offices in the city of Žilina, we selected only respondents from urban areas for further analysis. They are the respondents from the city district who prefer walking, rather than travelling by car. The results regarding the willingness of postal customers to travel the maximum distance from their place of residence to the nearest post office are shown in Fig. 2. We can see that 23% of respondents are willing to accept the maximal 5 minutes, 25% of respondents 10 minutes and 36% of respondents 15 minutes of the travelling by foot to the nearest post office. Generally, 84% of respondents are accepting maximal 15 minutes as time distance to travel by foot to the nearest post office.

As a result of the questionnaire survey, we found that potential customers from urban areas prefer walking as a way of the travel, in which they are willing to visit the post office at a maximum time distance to 15 minutes from the place where they are living.

Various display methods and imaging techniques can determine the servicing area of the post office. One of them is the so-called isochrone technique, which proceeds from the constant lines measured from the starting node to the target node. Areas of isochrones are mostly bounded by travel time (5, 10, 15, 30 min, etc.). This viewing mode is very illustrative, which can be considered as very positive. Another advantage of this method is that its usage does not apply to some, mostly administrative defined territorial units but is applied to real terrain [20]. Isochrone technique is, therefore, a suitable tool for modelling the availability of postal services and their connection with the population, in
which it is possible to find out the required number of inhabitants living in the areas bounded by the isochrones in specified time distances [21].

From the results of survey research was found that inhabitants with permanent residence at the city of Zilina wanted to visit their nearest post office in the pedestrian network within 15 minutes. For this reason, the availability of post offices in the city of Zilina will be modelled in maximal time distance up to 15 minutes. This distance will be divided (for better clarity) into three time intervals of 5 minutes, 10 minutes, 15 minutes. Fig. 3 shows the availability of all eleven post offices in the city of Zilina at the specified time intervals. The individual time intervals (that are shown in Fig. 3) are:

- interval up to 5 minutes, displayed in green;
- interval up to 10 minutes, displayed in yellow;
- interval up to 15 minutes, displayed in red.

Fig. 3 Isochrones (5, 10 and 15 minutes) around the Post Offices in Zilina

The availability of postal services in the city of Zilina, modelled by isochrones, showed weaker serviceability within the 15-minute distance of the population located in some city districts (Borík, Banova, Vranie, Mojsova Lucka, Rosinky, Trnove, Zadubnie, Zastranie and Zilinska Lehota). It means that the inhabitants living in these areas, for dealing with the postal office, have to overcome the time distance of 15 minutes by walking.

When we count the number of inhabitants allocated in the area of isochrones with the center in the post office, we can identify the level of importance (and density) of each post office. This number represents the level of availability of post offices for potential customers. The number of populations for the specific post office is shown in Table 1.

Table 1

<table>
<thead>
<tr>
<th>The Post office/Map position</th>
<th>The number of inhabitants serviced within the time distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>to 5 min</td>
</tr>
<tr>
<td>Post Office Zilina 1 (1)</td>
<td>1201</td>
</tr>
<tr>
<td>Post Office Zilina 2 (2)</td>
<td>958</td>
</tr>
<tr>
<td>Post Office Zilina 3 (3)</td>
<td>1090</td>
</tr>
<tr>
<td>Post Office Zilina 4 (4)</td>
<td>1162</td>
</tr>
<tr>
<td>Post Office Zilina 5 (5)</td>
<td>1402</td>
</tr>
<tr>
<td>Post Office Zilina 7 (6)</td>
<td>1103</td>
</tr>
<tr>
<td>Post Office Zilina 8 (7)</td>
<td>874</td>
</tr>
<tr>
<td>Post Office Zilina 9 (8)</td>
<td>780</td>
</tr>
<tr>
<td>Post Office Zilina 10 (9)</td>
<td>961</td>
</tr>
<tr>
<td>Post Office Zilina 14 (10)</td>
<td>711</td>
</tr>
<tr>
<td>Post Office Zilina 15 (11)</td>
<td>737</td>
</tr>
</tbody>
</table>
As it can be seen in Table 2, the largest population (12644 inhabitants) serviced within 15 minutes is in Post office Zilina 1, which is situated in the city center. On the contrary, the Post office Zilina 14, located in the city district of Brodno has the smallest number of inhabitants (2412 inhabitants) within 15 minutes of walking on foot.

Modelling the time availability of postal offices shows that some parts of the city are not accessible within a 15-minute walk. These "white spaces" are potentially suitable for the location of new postal offices. There are also city districts in Žilina, which are multiply covered by several post offices. Potential customers have the option which post office to use within the frame of a 15-minute walk.

Isochrone modelling, therefore, offers the possibility to identify specific post offices that are redundant in terms of availability and then build new post offices in places where availability is not sufficient. Post Office 2 and Post Office 5 could be identified as redundant post offices, i.e. post offices whose current serviced territory could be substituted by providing postal services from another post office. Moving identified post offices to new locations would ensure better general availability of postal services for the inhabitants of the city of Žilina. Therefore, it could be helpful to move Post office 2 to the Banova locality and Post Office 5 to the Hliny city district (see Fig. 4).

![Fig. 4 Isochrones (5, 10 and 15 minutes) around the Post Offices in Zilina.](image)

After moving both post offices to a new location, the number of residents who have access to mail within a 15-minute walk would represent the values given in Table 2. For the residents, that live in the areas serviced by moved Post Offices, are remained the availability of post offices in 15-minute walk distance. Post Offices 1, 10 and 3 are offering them the postal services on the same level of time availability.

<table>
<thead>
<tr>
<th>The Post office/Map position</th>
<th>The number of inhabitants serviced within the time distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>to 5 min</td>
</tr>
<tr>
<td>Former Post Office Zilina 2 (2)</td>
<td>958</td>
</tr>
<tr>
<td>New Post Office Zilina 2 (14)</td>
<td>1409</td>
</tr>
<tr>
<td>Former Post Office Zilina 5 (5)</td>
<td>1402</td>
</tr>
<tr>
<td>New Post Office Zilina 5 (13)</td>
<td>1439</td>
</tr>
</tbody>
</table>

The result of the isochrone modelling of post offices in Žilina city is increased general availability of postal services in Žilina and, therefore, a higher number of satisfied inhabitants.

3. Conclusions

The availability of services is an essential part of the solution of problems representing decision making of the optimal number and location of facilities on a given territory. Spatial interactions are used to calculate and predict the intensity of relations between two spatially separate locations but also used to determine demand and supply of services. Based on these facts, there are lots of different methods used to determine spatial availability. One of the
implementations of spatial and time availability of facilities providing postal services is isochrone modelling. From the results of realised survey research, we received maximal accepted time distance to the postal office for the inhabitants that live in the specified urban territory. This time distance of the wanted availability we presented on the defined territory by isochrone modelling technique. We can conclude, that with the usage of isochrone modelling techniques we can identify the post offices that are not well situated in the city and find them better locations for ensuring user required time availability (15-minute walk).

The data obtained from the post office availability modelling can be used as an initial step for further research, which can be focused on the determination of availability within another situation or different type of transport network. In this way, it is possible to point to areas where postal services are not available and to avoid this unacceptable situation. In this way, we can enhance the quality of the postal services provided within the stated Quality Requirements for Universal Service of the given country, but also increase the satisfaction of the postal operator's customers.

Acknowledgement

This contribution was undertaken as part of the research project VEGA 1/0721/18 Research on the Economic Impact of Visual Smog in Transport Using Neuroscience Methods.

References

The Impact of Cruise Shipping Pollution on Greenhouse Effect in the Port of Klaipeda

G. Martinkutė¹, A. Žukauskaitė², J. Žukauskaitė³, I. Paliakienė⁴

¹Lithuanian Maritime Academy, I. Kanto str. 7, 92123, Klaipeda, Lithuania, E-mail: g.martinkute@lajm.lt
²Lithuanian Maritime Academy, I. Kanto str. 7, 92123, Klaipeda, Lithuania, E-mail: a.zukauskaite@lajm.lt
³Lithuanian Maritime Academy, I. Kanto str. 7, 92123, Klaipeda, Lithuania, E-mail: j.zukauskaite@lajm.lt
⁴Lithuanian Maritime Academy, I. Kanto str. 7, 92123, Klaipeda, Lithuania, E-mail: i.paliakiene@lajm.lt

Abstract

Cruise shipping generates significant added value to the economy of the region as a whole. It expands tourism industry and promotes close cooperation between different sectors such as the city, seaport and tourism and ensures their smooth operation. As of 2014, Klaipeda is within the boundaries of a large port as are the ports of Oslo, Kiel, Riga, Gdansk, Kristiansand, Visby and Rostock by accepting more than 50 cruise ships each year (Cruise Baltic Market Review, 2018). Cruise shipping is part of the maritime transport sector, which was included in the Paris Agreement on Climate Change in 2016. There the target was set for the transport sector to reduce greenhouse gas emissions by at least 50% by 2050 compared to 2008 levels. When evaluating the development of cruise shipping and technical parameters of ships, it is also possible to estimate the amount of CO₂ that affects the greenhouse effect. The mass of air pollutants emitted from cruise ships is mainly generated in the ship’s power plant and depends on the vessel navigation phase: cruising, manoeuvring or hotelling. CO₂ emissions depend on the year of construction of cruise ship, ship’s length, gross tonnage, power of ship’s marine propulsion engine and number of passengers. Taking into account the results of fuel consumption and CO₂ emissions of the cruise ships analysed over the whole period under research, it was found that from 2014 to 2018 the fuel consumption increased by almost 8% (from 2.9 t to 3.1 t), and CO₂ emissions were also found to be 8% (from 9.2 t to 9.9 t). The investigation showed that new-build cruise ships consume up to 60% less fuel and the same percent less of CO₂ emissions compared to ships built in 1977-1990. When assessing the impact of cruise shipping on the city of Klaipeda, two distances are used in the calculations – from the gate of the Port of Klaipeda to the terminal assigned to the ship. The results of the study show that the total amount of greenhouse gas (GHG) emissions from cruise ships is not decreasing during the research period in the Port of Klaipeda. Recalculation of fuel consumption and CO₂ emissions per passenger has shown that larger cruise ships carrying more passengers emit relatively less CO₂. Summarizing the recalculated indicators per passenger, it can be stated that more powerful ships consume 18-25% less fuel, this results in the same percentage reduction in CO₂ emissions.

KEY WORDS: Cruise shipping, CO₂ emissions, Greenhouse effect

1. Introduction

Comparing the amount of CO₂ emitted from the different transport sectors, the maritime transport ranks second, after the road transport. Therefore, in 2018, the maritime transport sector was included in the Paris Agreement on Climate Change. The target has been set to reduce greenhouse gas emissions from ships by at least 50% by 2050 compared to 2008 levels, although it has been suggested to reduce even 70% until the end of the same period. This is a major challenge for the entire shipping industry, thus, first of all, its implementation requires to assess the current technical parameters of ships and pollution generated. One of the main causes of climate change is greenhouse gases that enter the atmosphere (GHG). Large amount of these gases are formed naturally, however human activities significantly increase their amount in the atmosphere. As a result, greenhouse gases change the established balance and this has a negative effect on the environment. Carbon dioxide (CO₂) accounts for the largest part of total GHG emissions, but other gases such as methane (CH₄), chlorofluorocarbons (CFCs), nitrous oxide (N₂O) are also very important. Carbon dioxide (CO₂) is a gas that controls the Earth’s atmospheric temperature [6]. In countries with the high industrial outputs, the amount of CO₂ emitted accounts for more than 80% of greenhouse gas emissions [13]. The mass of air pollutants emitted by ships is mainly generated by ships’ power plants, which burn fossil fuel, i.e. petroleum products, coal or natural gas. Liquid petroleum products are the most dominant in marine energy, such as heavy (IFO, HFO, MFO), middle (MDO) and light (MGO) [14]. Total CO₂ emissions from ships increased from 910 to 932 million tons from 2013 to 2015. (+ 2.4%). In 2015, total shipping emissions accounted for 2.6% of global CO₂ emissions from fossil fuel use and industrial processes [11]. According to 2018 statistics provided by the European Environment Agency [3] (EEA), in Europe, of all existing transport sectors, pollution from maritime transport accounts for 13.6% of GHG emissions.

In 2018, more than 150 Member States attended the meeting in London, at IMO headquarters, when the initial strategy on the reduction of GHG emissions from ships was adopted, setting out a vision on how to do it as soon as possible. Several countries of the European Union have proposed a decision to reduce emissions from the maritime transport sector by 70% by 2050. However, the shipping industry, represented by the International Chamber of Shipping
(ICS), has announced the proposal to reduce emissions from ships by 50% by the previously proposed period. In order to limit the average global warming well below 2°C, compared to the pre-industrial times, and make efforts to maintain the global average temperature increase below 1.5°C, would be considered as a successful beginning [4, 5]. In order to take action and change the resulting situation, the maritime transport sector was also included in the Paris Agreement on Climate Change in 2018, and one of the goals is to reduce the temperature rise to 1.5-2°C by 2050, and ships will have to reduce their GHG emissions by at least 50%. Although there are about 50,000 ships of various types in the world, and cruise ships account for a relatively small share (~0.7%), according to the analysis of shipbuilding trends, passenger needs and economic benefits – the number of cruise ships will increase and cruise shipping will be responsible for an increasing share of GHG emissions.

2. Methodology

The research assessed the amount of CO₂ emissions of cruise ships that have entered the Port of Klaipeda from 2014 to 2019. The calculations were based on the methodology proposed by the European Association for Forwarding, Transport, Logistics and Customs Services, which contains the calculation of greenhouse gas emissions for freight forwarding and logistics services, according to the European Committee for Standardization (CEN) standard EN 16258 [8]. The total CO₂ emissions of cruise ships were estimated by the ship navigation phase (cruising, manoeuvring, hotelling) [15]:

\[
E_{\text{trip}} = E_{\text{cruising}} + E_{\text{manoeuvring}} + E_{\text{hotelling}},
\]

where \(E_{\text{trip}}\) – CO₂ emission over a complete trip (tonnes); \(E_{\text{cruising}}\) – CO₂ emissions during cruising (tonnes); \(E_{\text{manoeuvring}}\) – CO₂ emissions during manoeuvring (tonnes); \(E_{\text{hotelling}}\) – CO₂ emissions during hotelling (tonnes).

Data used for calculations: list of cruise ships (2014-2019), i.e. names, number, number of entries [10]; time spent by cruise ships in the Port of Klaipeda [12]; technical parameters of cruise ships, i.e. main engine power, auxiliary engine power, gross tonnage, etc. [9] (database of Lloyd’s Register); emission factor; engine loads factors by navigation phase.

Using data from the Lloyd’s register on the technical parameters of ships, the amount of CO₂ was calculated according to the Eq. 2:

\[
E_{\text{trip},i,j,m,p} = \sum_p \left[ T_p \times L F_e \times E F_{e,i,j,m,p} \right],
\]

where \(E_{\text{trip}}\) – CO₂ emission over a complete trip (tonnes); \(P\) – engine nominal power (kW); \(LF\) – engine load factor (%); \(EF\) – emission factor (kg/kW); \(T\) – time (h); \(e\) – engine category (main, auxiliary); \(i\) – pollutant (in this case – CO₂); \(j\) – engine type (slow-, medium- or high-speed diesel, gas turbine or steam turbine); \(m\) – fuel type (marine diesel oil (MDO)); \(p\) – different phase of trip (cruise, manoeuvring, hotelling).

The values of the emission factors required in order to use Eq. (2), are set out in the European Commission Delegated Regulation (EU) 2016/2071[7]. Different ships use different types of fuel. Cruise ships mostly use marine diesel oil (MDO). GHG emissions, in this case CO₂, are calculated using the emission factors presented in Table 1.

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Emission factor (t-CO₂/t-fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel/gas oil</td>
<td>3.206</td>
</tr>
<tr>
<td>Light fuel oil</td>
<td>3.151</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>3.114</td>
</tr>
</tbody>
</table>

The calculation of fuel consumption was based on the formulas provided by C. Trozzi [15] and standard EN 16258 [8], when multiplying parameters such as time spent in the relevant navigation phase, engine power and load factors. In order to assess the ship’s time spent in the different navigation phases, data such as the average speed of a ship \(V_z\), and the distance travelled \(S_z\), are required (Eq. (3)).

\[
T_z = \frac{S_z}{V_z}.
\]

The speed of ships in the port area is limited, thus, the average speed of a cruise ship in the port water area is taken which is equal to 6 knots per hour (11.11 km/h). The distances used in the study are divided into three main categories (Table 2). The loads of the main and auxiliary engines used differ in the respective navigation phase. The loads used for the calculations are presented in Table 3.

GHG emissions were analysed according to the classification of cruise ships (Table 4), ship engine powers, year of construction, and other parameters. Classification No. 1 [1], Classification No. 2 [2]:

<table>
<thead>
<tr>
<th>Classification No. 1</th>
<th>Classification No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Class A</td>
</tr>
<tr>
<td>Class B</td>
<td>Class B</td>
</tr>
<tr>
<td>Class C</td>
<td>Class C</td>
</tr>
<tr>
<td>Class D</td>
<td>Class D</td>
</tr>
<tr>
<td>Class E</td>
<td>Class E</td>
</tr>
<tr>
<td>Class F</td>
<td>Class F</td>
</tr>
<tr>
<td>Class G</td>
<td>Class G</td>
</tr>
<tr>
<td>Class H</td>
<td>Class H</td>
</tr>
<tr>
<td>Class I</td>
<td>Class I</td>
</tr>
<tr>
<td>Class J</td>
<td>Class J</td>
</tr>
<tr>
<td>Class K</td>
<td>Class K</td>
</tr>
<tr>
<td>Class L</td>
<td>Class L</td>
</tr>
<tr>
<td>Class M</td>
<td>Class M</td>
</tr>
<tr>
<td>Class N</td>
<td>Class N</td>
</tr>
<tr>
<td>Class O</td>
<td>Class O</td>
</tr>
<tr>
<td>Class P</td>
<td>Class P</td>
</tr>
<tr>
<td>Class Q</td>
<td>Class Q</td>
</tr>
<tr>
<td>Class R</td>
<td>Class R</td>
</tr>
<tr>
<td>Class S</td>
<td>Class S</td>
</tr>
<tr>
<td>Class T</td>
<td>Class T</td>
</tr>
<tr>
<td>Class U</td>
<td>Class U</td>
</tr>
<tr>
<td>Class V</td>
<td>Class V</td>
</tr>
<tr>
<td>Class W</td>
<td>Class W</td>
</tr>
<tr>
<td>Class X</td>
<td>Class X</td>
</tr>
<tr>
<td>Class Y</td>
<td>Class Y</td>
</tr>
<tr>
<td>Class Z</td>
<td>Class Z</td>
</tr>
</tbody>
</table>
Table 2

<table>
<thead>
<tr>
<th>Distance</th>
<th>In nautical miles</th>
<th>In kilometres</th>
</tr>
</thead>
<tbody>
<tr>
<td>From the exclusive economic zone to the gate of the port</td>
<td>12</td>
<td>22.22</td>
</tr>
<tr>
<td>From the gate of the port to the Cruise ship terminal</td>
<td>2.45</td>
<td>4.54</td>
</tr>
<tr>
<td>From the gate of the port to the Central Klaipeda terminal</td>
<td>3.65</td>
<td>6.76</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Navigation phase</th>
<th>Main engine load (%)</th>
<th>Auxiliary engine load (%)</th>
<th>Main engine operation time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruising</td>
<td>80</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Manoeuvring</td>
<td>20</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Hotelling</td>
<td>20</td>
<td>40</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Classification No. 1</th>
<th>Classification No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel size</td>
<td>Gross tonnage</td>
</tr>
<tr>
<td>Very small</td>
<td>less than 10 thsd.</td>
</tr>
<tr>
<td>Small</td>
<td>10-32 thsd.</td>
</tr>
<tr>
<td>Large</td>
<td>-</td>
</tr>
<tr>
<td>Mega</td>
<td>92-220 thsd.</td>
</tr>
</tbody>
</table>

3. Analysis of CO₂ Emissions from Cruise Ships

The research assesses the amount of fuel consumed and the amount of CO₂ emitted by cruise ships that arrived in the Port of Klaipeda from 2014 to 2018. Taking into account the five year period under research, it can be stated that on average the Port of Klaipeda is visited annually by about 57 cruise ships with 74 thousand seats for passengers. The analysis presents the decrease in the number of cruise ships in the first three years of the investigation, but the number of passengers increased during the same period (Fig. 1). This happened because the Port of Klaipeda was visited by larger cruise ships, technically capable of carrying more passengers.

![Fig. 1 Number of cruise ship calls in the Port of Klaipeda from 2014 to 2018 and their maximum passenger capacity](image_url)

According to the situation, when the number of vessels is smaller but the maximum number of passengers on board is higher, it can be assumed that the gross tonnage of vessels is also increasing. Comparing the beginning and the end of the research period, the number of small vessels is decreasing. In total, there were 66 (19.2%) ships of such size (up to 25 thousand tons), and the number of very small vessels (up to 5 thousand tons) ships slightly increases. In total, there were 48 ships up to 5 thousand tons in the Port of Klaipeda. In 2019, 11.1% more ships of such size arrived.

Analysing the collected data on the main engine power of cruise ships that arrived in 2014-2019, the ships were grouped as follows: up to 10 thousand kW – not powerful, up to 20 thousand kW – medium-powerful, up to 40 thousand kW – powerful, up to 80 thousand kW – very powerful.
The Port of Klaipeda is mostly visited by very powerful cruise ships. Although the number of very powerful cruise ships decreased in 2018, the largest number of ships arrived in 2019, during the whole research period. The number of powerful cruise ships was fairly even until 2019, when there was the sudden increase from 12 to 23 units, and it fell by 6 units in 2019. There were 108 very powerful cruise ships, which makes up 31.4% of all ships, 94 (27.3%) powerful ships, 84 (24.4%) medium-powerful and 58 (16.9%) not powerful ships (Fig. 2). According to the results, it can be stated that the higher the gross tonnage of the ship, the more powerful the main engine, and consequently the emissions are higher.

After analysing the data of 2014-2018 on cruise ships arrived at the Port of Klaipeda and time spent in the port territory, the graph has been drawn depicting the frequency of cruise ships that spent a certain period of time (Fig. 3). Out of 288 cruise ships, 116 (40.4%) ships spent from 10 to 12 hours in the Port of Klaipeda. 77 ships, representing almost 27% of all cruise ships, spent from 8 to 10 hours, and 53 ships (18.5%) spent from 12 to 14 hours in the port. The remaining 25 (8.7%) and 10 (3.5%) cruise ships spent from 5 to 8 or from 14 to 17 hours, respectively.

Taking into account the previously analysed technical data of cruise ships arrived in the Port of Klaipeda since 2014, fuel consumption calculations were performed. Based on the calculations, it is possible to estimate the current amount of pollution from cruise ships in the Port of Klaipeda. Fuel consumption was calculated for each vessel by estimating the distance travelled, the power of the main and auxiliary engines and their operating time. According to C. Trozzi’s methodology, the load factor was considered to be 80% for the main engines during the cruising phase, and 20% for both the manoeuvring and hotelling, and 30% for the auxiliary engines during the cruising, 50% during the manoeuvring and 20% for the hotelling. Initial calculations were performed to determine the amount of fuel consumption of cruise ships for the distance under study, i.e. from Klaipeda Exclusive Economic Zone to the berth assigned to the cruise ship and back.

During the whole investigation period, the highest fuel consumption was in 2017, when the number of cruise ships arrived was the highest – 63. In 2014, 63 cruise ships also arrived, but fuel consumption was 16.5% lower than in the
previous mentioned year. One reason for this difference in fuel consumption could be the assignment of different berths to cruise ships. In 2014, only 2 cruise ships moored at the berth 80 in the Central Klaipeda terminal, which is located further from the Cruise ship terminal, and 4 cruise ships in 2017. This difference is also due to the fact that the main engine power of cruise ships arrived in 2014 was lower than of cruise ships arrived in 2017.

The analysis of the amount of fuel consumption according to the ship’s main engines leads to the conclusion that the more powerful the engine, the less fuel consumption can be attributed to one passenger, as the ship’s parameters are correspondingly higher and can accommodate more passengers.

The power of the main engines of all cruise ships arrived in the Port of Klaipeda during the research period does not exceed 80 thsd. kW. Comparing the amount of fuel consumption by the main engine categories (Fig. 5), it should be mentioned that during the whole research period the total minimum fuel consumption falls to 20 thsd. kW for the main engine category 3.4 t fuel.

However, calculating the amount of fuel for the same engine category that can be assigned to one passenger, the maximum indicator is 0.297 kg fuel/passenger (Table 5). Cruise ships with the main engine power from 20 to 40 thsd. kW consume the most fuel, however, the fuel consumption per passenger is lower than in the above mentioned category, when ships used the least fuel.
After estimating the fuel consumption of cruise ships and the distribution of CO₂ emissions according to the navigation phases, the fuel consumption and CO₂ emissions according to the year of construction were assessed.

Fig. 7 Total results of fuel consumption and CO₂ emissions per passenger of cruise ships for the whole research period by year of construction

The highest fuel consumption is recorded in the category of the latest cruise shipbuilding year, when the total fuel consumption reaches almost 6.5 t, and the CO₂ emissions – even 20.7 t and these results represent 100 cruise ships built in 2005-2018, which arrived in the Port of Klaipeda from 2014 to 2018 (Fig. 7). The lowest indicators are obtained for the oldest built cruise ships in the first category (1948-1962), when the results respectively were 194.1 kg and 622.5 kg.

Such vessels arrived at least over five years to the Port of Klaipeda – 13. However, the results change, when estimating the number of passengers carried and calculating fuel consumption and CO₂ emissions per passenger. It is important to mention that the results obtained for both fuel consumption and CO₂ emissions per passenger change the above mentioned overall results. The lowest quantities are recorded in the category of most recently built cruise ships (2005-2018), with fuel consumption of 0.144 kg/passenger and 0.463 CO₂/passenger, respectively. The highest results are recorded for the middle category – cruise ships built in 1977-1990, although only 37 such cruise ships arrived in the Port of Klaipeda during the whole research period. Newly built cruise ships use as much as 60% less fuel and emit the same percentage less of carbon dioxide compared to the mid-year category of cruise ship construction. However, comparing the maximum number of passengers carried by both categories of ships, it can be stated that the most recently built cruise ships carried 88.2% more passengers (2 million 21.6 thsd) than cruise ships belonging to the above-mentioned medium category (26.1 thsd). Summarizing the recorded indicators per passenger, it is concluded that ships that are more powerful, newer and carrying more passengers use significantly less fuel, resulting in far less CO₂ emissions into the atmosphere.

4. Conclusions

After analysing cruise shipping in 2014-2018 in the Port of Klaipeda, it can be stated that the number of arriving cruise ships to the Port of Klaipeda is decreasing, and the number of passengers is increasing. Taking into account the results of fuel consumption and CO₂ emissions of the analysed cruise ships during the whole research period, it was found that from 2014 to 2018 fuel consumption increased by almost 8% (from 2.9 t to 3.1 t), and CO₂ emissions also increased by 8% (from 9.2 t to 9.9 t). Cruise ships of newer construction have been found to use up to 60% less fuel and emit the same percentage less of CO₂ compared to ships built in 1977-1990. Recalculation of fuel consumption and CO₂ emissions for the number of passengers carried has shown that larger cruise ships carrying more passengers emit less CO₂. Summarizing the recalculated indicators per passenger, it is concluded that more powerful ships use 18-25% less fuel, leaving the same percentage less of CO₂ emissions in the atmosphere. For example, ships with the main engine power of up to 20 thousand kW emit 50% more of CO₂ than ships with the main engine power of 60 to 80 thousand kW.

References

   The Demand and Economic Environmental Social Impacts of Australian Cruise Tourism

Viewpoint on Cybersecurity in FRMCS

M. Sumila

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

Abstract

The article presents the current state of knowledge of the next generation of the railway radio communication system (FRMCS) and its impact on the safety and security of the railway. The following sections describe the status of work on the new standard and the scope of applications. Next, put into consideration the impact of the new radio system on security in various areas. The second part of the article indicates the methods applied to the system to improve security in the field of technological mechanism, system architecture and applications.

KEY WORDS: FRMCS, cybersecurity, new technologies

1. Introduction

Future Railway Mobile Communication System (FRMCS) is the future radio communication standard introduced by UIC (fr. Union Internationale des Chemins de fer). FRMCS will replace GSM-R as a common, unified railway radio communication standard for railway in European countries and it is under EU Commission TSI regulation i.e. TSI CCS (Technical Specification for Interoperability relating to the ‘Control-Command and Signalling’ subsystem of the rail system in the European Union).

Decision to start work on the new communication standard and to give up GSM-R was difficult. For over 10 years, GSM-R was believed to ensure rail interoperability. These days, in countries such as Poland, the network is still under implementation. On the other hand, GSM-R is already outdated in a technological sense. It originates from GSM 2G / 2.5G technology which was created about 30 years ago. It offers low data transmission speeds (<56 kb/s), low network capacity (19 radio channels in the UIC band), and low broadband interference immunity. In addition to this, the horizon of manufacturers’ support is limited until 2030. Problems with network capacity in the area of individual cells and susceptibility to radio interference from the wideband public network have become particularly painful for railways [24]. The first aspect had an impact on the congestion effect in railway areas. The effect became especially problematic in the areas of intense shunting. As a consequence, the railway operators still prefer analogue radio technology than dedicated to railways GSM-R mobile communication. The second problem was diagnosed in the second decade of the 21st century. Its reason lies in the technological development of public cellular networks. The implementation of GSM 3G and GSM 4G technology by the public networks affects in GSM-R receivers by arising intermodulation interference and blocking. For GSM 2G technology this phenomenon can only be mitigated. In this regard, UIC decided to develop the new railway radio standard, which will be FRMCS.

Officially, UIC started work on the system in 2012. The standard is being developed in close cooperation with different stakeholders from the rail sector, among others ERA, Unife, CER, Shift2Rail, EIM and standardization organizations (CEPT, 3GPP, ETSI, ITU). Railway manufacturers (including Siemens, Bombardier, Nokia, Kapsch, Thales, Alstom) have also joined the work. There were also railway managers (among others SNCF, NetworkRail, DB, AZD Praha, Trafikverket, CAF, CFW). The most important publications include the following works [4-13, 27]. A number of technical reports are currently available describing the frame of the future standard. Current specifications include documents [26, 28, 29].

In general, the standard is a far-reaching solution designed to provide conditions for the convenient operation of railways by managers, employees and also passengers [25]. FRMCS will be open to new technologies and services outside the scope of railway control. For example, it will provide passengers various types of information, including Internet access. It is said that “FRMCS is a key to a full introduction of rail transport into digitalization future” but it is a huge challenge in a conceptual sense as well as in the field of cybersecurity.

The following part of the article briefly describes the essence and status of work on the standard. The second section discusses the main areas of vulnerability of the new system to cyberattacks and after that, the author presents methods used to protect network and information in the new railway radio system based on available information.

2. Impact of FRMCS on Security

According to the IEC 62443 [21], the network security is composed of three pillars: technology, process and people. The technology is considered as a set of resources used to uphold availability, integrity and confidentiality. The process involves a set of guidelines and standards for procedures that can be used to ensure security. People need to be trained to perform assigned roles and bear the responsibility but one needs to remember that also other users will have access to the network. The following parts of this chapter analyse the key features of this system for security.
2.1. Impact of Radio Technologies on Security

FRMCS is intended to be an evolutionary standard. At the beginning of work on the standard in the second decade of the XXI century it was known that GSM 4G technology will be replaced by a new GSM 5G standard. However, at that time, the specification for the GSM 5G network was not fully known. Therefore, FRMCS is being created according to the principle where more important are applications of the use the railway communication system, than radio technology and its parameters. In this way radio standard must be compatible with the required level of railway service. Another issue is the need to comply with the existing GSM-R standard, which aims to maintain the overarching goal of interoperability of the railway system without significant changes to existing user interfaces.

Based on the technical reports issued so far, GSM 4G as well as GSM 5G technology may be used in FRMCS. The use of GSM 4G is to be temporary. GSM 4G should be used wherever it will not be possible to implement the GSM 5G network as an FRMCS radio technology in the railway area.

The analysis of the impact of the radio technologies used in FRMCS on security should pay additional attention to the possibility of using other radio access technologies. At present, IEEE 802.11 and IEEE 802.16 [19-20] are the most frequently considered technologies but the list is not and will not be closed to other standards. The inclusion of these technologies in FRMCS aims to provide services and access to the network for public users whose terminals will not be compatible with the FRMCS radio network. In this case, the mechanisms of protection and security of these networks are dubious, because these networks lack the expected security mechanisms. The third section will discuss the measures taken to increase the security level of the FRMCS network.

2.2. Impact of the Application on Security

FRMCS system is supposed to enable wide access to various types of applications. Among them, there is a group of key applications for train safe control. These applications enable the integration of various types of IT devices and systems. Violation of the basic security attributes indicated in ISO 27001 [22], i.e. their availability, integrity and confidentiality, may have an impact on railway safety. This may occur after an attack on the system and a deliberate change of values determining the condition of technical devices or systems responsible for safe train running. This is favored by the broad integration of many different solutions whose communication is envisaged through FRMCS. The use of devices connected to the train communication network (TCN) in railway vehicles, many different devices communicating via short-range devices (SRD) and the Internet of things (IoT) opens new paths to cyberattacks.

User Requirements Specification (URS) [28] defines the general flow of information between users and applications in the FRMCS network. Figure 1 shows the complexity of relationships between users and devices in the FRMCS network.

![Fig. 1 Diagram of the relationship in the FRMCS application layer (cited from URS 4.0 [28])](image)

The FRMCS should support, among others, the following applications: passenger information, on-board...
systems, passenger connectivity, passenger data, train crew connectivity, safety and security, CCTV, signalling, autonomous and remote vehicle operation, maintenance staff connectivity, electronic signage, wayside objects and sensors, level crossings and virtual coupling.

2.3. Users Impact on FRMCS

Users are the first source of security threats. It is worth noting that the group of FRMCS users and their access has been significantly expanded compared to previous generation railway radio systems. This approach is part of the world’s vision of information society and rapid development of Intelligent Transportation Systems (ITS) together with computerization of vehicles are proof of it [23]. These systems are designed to provide various road, air, rail and maritime information with the help of ICT (Information and Communication Technologies) devices and tools enabling more efficient fleet management, optimization of resources. ITS is also very important for passengers because it gives them access to the information they expect. We often use the ITS systems today, without the knowledge of using it. The use of the GSM-R network has hampered ITS deployment in the rail area so far. The main reason was the transfer of the train control system and the low transmission rate of the radio channel. The assumption is that FRMCS will be used by rail services, business and passengers. Especially the last group of users can be a source of danger mainly due to their anonymity.

3. Security in FRMCS

Based on previous information, we know that FRMCS is a large undertaking affecting many different areas related to the transmission of messages. For FRMCS, the security aspect is related to protecting the telecommunication network that works as a carrier of signalling data, notably shielding the underlying networking infrastructure from unauthorized access, misuse, malfunction, modification, destruction or improper disclosure.

The URS [28] describes fundamental principles that are accompanied by guides that have been considered in the document. Principle 8 deals with security related issues in the areas of:

- prevention of unauthorised and potentially malicious acts affecting the use of the communication system and any associated data;
- applications that require strong authentication, encryption and key management methods and the communication system shall support these when required;
- application access configuration within the system based upon the permissions associated with each authorised user;
- mitigation of cyber security threats.

In the Use cases document [29] section 5 the security framework is considered in the following fields:

- services provided by the FRMCS system;
- bearer of flexible access including 3GPP as well as non-3GPP access;
- direct interaction between FRMCS equipment;
- interaction between the FRMCS end user devices and the FRMCS network;
- interaction between the FRMCS network functions;
- stored data within the FRMCS System;
- interworking between an FRMCS system and another FRMCS system;
- interworking between an FRMCS system and a legacy system.

In the process of identifying management, authentication, authorization, key management, data protection (regarding integrity, confidentiality, privacy, non-reputation), prevention of attacks, detection of attacks, the reaction on detected attacks, it is assumed that the system should be secure. In the document [29] there are still gaps that need to be analysed, explained and described in future technical specifications.

3.1. Application Security in FRMCS

URS [28] defines over 100 different applications and divides them by type into: “Comms” i.e. communication application and “Support” i.e. supporting the application of communication application(s). Each of the indicated groups is categorised 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.

The introduced division allows the application to be differentiated due to its importance and purpose. Each application has various parameters connected with: data type, link symmetry, distribution, bandwidth, delay, vehicle speed and reliability. Finally, it gives the possibility of different treatment and protection of the group of critical applications designed for railway safety from the business one. The classification of applications also had an impact on FRMCS architecture.
3.2. Architecture Security

At the architectural level, FRMCS has its mechanisms that affect the security of transmitted data. The following technical studies are currently known [1, 2, 14]. These documents draw the architecture of the FRMCS system, which adopts a different principle of transmission of data over the network in the case of Mission Critical services (MCX) and non-critical services (Non-MCX). The MCX services provide point-to-point and group communication for voice, data and video to manage railway applications. The 3GPP MCX framework functions support FRMCS User registration and flexible addressing including i.e. functional aliases, location management and communication logging. In addition, the 3GPP MCX framework requires an extension for supplementary services [18] and the capability for recording voice and data sessions, which might be defined by upcoming 3GPP releases or need to be captured in ETSI TC RT specifications. Non-MCX is a subset of the FRMCS System that provides simple connectivity by using the FRMCS communication services and railway services. The described concept was presented on the basis of the ISO/OSI layered model in Fig. 2.

Fig. 2 Reference model of the FRMCS System (cited from ETSI TR 103459 [14])

According to the technical report, ETSI TR 103 459 [14] FRMCS Communication Services obtain from FRMCS Transport System the required communication priority, latency and reliability. For the Non-MCX applications, only the FRMCS Transport Layer is used in order to send and receive data within FRMCS Communications Services.

Every application which is critical for railway (MCX) for security reasons need to be authenticated and received an FRMCS User Identity linked to MCX functional alias. This association allows us to connect with an appropriate application profile that relates to permissions and authorization for using features or communicating with other FRMCS identities. For such applications, each communication needs a separate FRMCS User Identity and only if the application has the authorization or sufficient permission the communication is granted. Application request communication services through a control messaging within the FRMCS system which makes a single data connection available. It might be based on a multi-path or redundant connection using one or more physical radio bearers. Using the MCX control messaging decouples the applications from the radio technology and enables a flexible interaction with the communication services. Finally, FRMCS supports secure data transmission and an MCX enabled application inherits its features without extra communication security protocols or features. The technical report ETSI TR 103 459 [14] notes that a common secure communication function also improves the interoperability between on-board and trackside subsystems.

3.3. Technology Security

It is assumed that FRMCS is a system independent of radio technology. In the technical report ETSI TR 103 459 [14] from 2019, reference was made to two most frequently indicated public radio technologies aspiring to be used in FRMCS, i.e. GSM 4G and GSM 5G. Documents [15] and ongoing [16] suggest the possibility of using these technologies for the needs of FRMCS. The latter one [17] is based on the GSM 5G system architecture specification.

The use of GSM 4G technology allows us to use authentication through the procedure EPS AKA (Enhanced Packet System – Authentication and Key Agreement) used in GSM 4G networks for mutual authentication between users and networks. At the level of Non-Access Stratum (NAS) Security, GSM 4G allows to securely deliver signalling messages between Users Equipment (UE) and Mobile’s Management Entity (MME) over radio links and it performs integrity check (i.e. integrity protection/verification) and ciphering of NAS signalling messages. Different keys are used for integrity checks and for ciphering. While integrity check is a mandatory function, ciphering is optional. NAS
security keys, such as integrity key (KNASint) and ciphering key (KNASenc), are derived from UEs and MMEs from KASME. Access Stratum Security is introduced to ensure the secure delivery of data between a UE and an evolved NodeB (eNB) over radio links. It conducts both integrity checks and ciphering of Radio Resource Control (RRC) signalling messages in the control plane, and only ciphering IP packets in the user planes. It allows us to use different keys for integrity check/ciphering RRC signalling messages and ciphering IP packets. To sum up, in the 4G network there are mechanisms to secure data transmission against unauthorized access to the network and messages, but not all are launched as standard.

In the GSM 5G network there are more advanced security methods. For example, in GSM 5G exists a network and a device allowing mutual authentication based on primary authentication. This mechanism is similar to GSM 4G but it is more advanced. The authentication mechanism has an in-built home control allowing the home operator to know whether the device is authenticated in a given network and to take the final call of authentication. In railway this functionality would be particularly useful for trains roaming onto another railway network. Primary authentication is an independent radio access technology, thus it can run over non-3GPP technology such as IEEE 802.11 [19]. It would allow authentication to be consistent across the various flexible bearers. Secondary authentication is for authentication with data networks outside the mobile operator domain. For this purpose, different Extensible Authentication Protocol (EAP) based authentication methods and associated credentials can be used. A similar service was possible in GSM 4G as well, but in GSM 5G it is integrated into the system architecture. In addition to this, from the very beginning of work on GSM 5G, the aspect of security has been implemented by the inter-operator interface which comes from SS7 (Signalling System no. 7) and has been previously used by mobile communication systems. In the field of privacy the subscriber identity issue has been known since the first generation of cellular mobile systems but in GSM 5G a privacy solution has been developed at the stage that the user's subscription identifier is permanently protected against active attacks. A home network public key is used to provide subscriber identity privacy. The GSM 5G core network is based on a service based architecture, which did not exist in GSM 4G and earlier generations. Thus GSM 5G also provides adequate security for Service Based Architecture (SBA).

To achieve full control over not only the before-mentioned but also the future radio resources, it has been decided to adopt the concept of Network Slicing. The concept was described in ETSI TR 103 459 [14] and it is built upon network sharing and refers to the creation and operation of multiple virtual end-to-end networks, tailored to specific use cases or business models on a common physical communications infrastructure. A network slice can span all domains of the network, from the radio access via the backhaul transport network to the core functionality, and encompasses specific control and user plane handling needed for each slice.

In FRMCS, System Network Slicing goes a substantial step further because it allows composing a completely different network functions and configurations for different slices. Furthermore, each slice may have a largely individual management and orchestration setup and corresponding responsibility split between the involved players [14].

4. Conclusions

Security in the railway radio system is not synonymous with rail safety. With regard to RAMS standards [3], such a system does not affect safety. However, the safety principle is maintained under the conditions of reliable sources of information. The threat in the aspect of security calls into question the reliability of the data obtained from the railway control system. In this regard, it is important to maintain a high level of authorization, confidentiality and data integrity in key data transmission systems.

The FRMCS system is particularly vulnerable due to planned network flexibility, a large number of devices and using it as a medium for access to the Internet network, the possibility of using various radio technologies including their security mechanisms’ and network virtualization. An extended group of future network users, including non-rail users, may also have an impact on security. For these reasons FRMCS designers have taken various measures to ensure security. On the technological level, built-in security mechanisms of GSM 4G and 5G radio systems have been used. At the system architecture level, the division of services into MCX and Non-MCX has been introduced, and finally, at the application level, the services have been divided according to their purpose.

To this day, full system specification is not known, but in special cases it is admitted that the indicated security methods may not be sufficient. In such cases, an appropriate solution would be only to use end-to-end encryption between the communicating parties.

References

5. EIM, 2019. ERTMS/FRMCS migration strategy.
8. ERA, 2016. Study on Coexistence of GSM-R with other systems.
9. ERA, 2016. Study on Migration from GSM-R to other solutions.
11. ERA, 2017. Study on Implications of bearer independent communication concept.
18. ETSI TS 124 010, 2017. Digital cellular telecommunications system (Phase 2+) (GSM); Universal Mobile Telecommunications System (UMTS); LTE; Mobile radio interface layer 3; Supplementary services specification; General aspects. ver. 14.0.0 (3GPP TS 24.010).
28. UIC, 2019. FRMCS - User Requirements Specification. ver. 4.0.0.
29. UIC, 2019. FRMCS - Use Case Specification. ver. 1.0.0.
Abstract

Abstract: This article deals with the proposal of the examination credits granting procedure for aircraft maintenance technicians based on educational attainment. Regulations enable us to grant some of the theoretical exams. Otherwise, the technician must pass these exams via written tests. The first part of the article is about descriptions of the topic and the current situation in the Czech Republic. The second part, which also is the main part, is about the proposal of the credits granting procedure itself. There is a detailed description of the procedure together with a flowchart, and a description of procedure processes in this part. The last part is about a discussion and summarizing of the proposed procedure. The goal of this article is not to criticize national or European aviation authorities but an effort to unify the EU regulations implementing in all member states. The authors react to a situation that occurred in the first quarter of the year 2020 in the CZ. They try to find a solution that would be acceptable by all affected parties.

KEY WORDS: examination granting, modules granting, PART 66, maintenance technician exams, theoretical exams, examination credits

1. Introduction

For obtaining an aircraft maintenance technician license in the European Union (EU), several conditions must be fulfilled according to Commission Regulation (EU) No 1321/2014 [1]. The basic conditions are to have sufficient practice and to pass theoretical exams in several subjects, hereinafter referred to as modules. Applicants for a license need not be subject to any united theoretical training. In practice, this means that the aircraft maintenance technician can be both a university educated person and a high school student directly in the field of aircraft maintenance technicians, as well as another non-technical field (cook, painter, etc.). Therefore, the level of education of applicants can be very different. This is also reflected in Regulation [1], which allows granting certain modules. Each EU country has the opportunity to apply for these credits in a slightly different way. There is no united detailed description of the credits granting either in the AMC and GM, in the recommended and advisory documents. The unification of the procedure should be ensured by the quality system and audits performed by EASA. Unfortunately, not all EASA auditors have a common view on this matter. In practice, there are relatively large differences in the conditions for the credits granting across member states.

This article deals with the possibility of how it would be possible to eliminate these shortcomings. It proposes a procedure that can be implemented in the current system in place without the need to amend the EU Regulation [1].

2. Current State

The impulse for the creation of this article was, besides other things, the issuance of the CAA-ZLP-121 AML PART-66 procedure [3] by the Civil Aviation Authority (CAA) to fulfil EU regulations. This procedure sets out new rules for:

- transformation of the original Czech AML ICAO and AML JAR-66 to AML PART-66;
- renewal of AML PART-66;
- issuance of new AML PART-66;
- change of AML PART-66 and their extension by new (sub) categories and qualifications;
- cancellation, suspension and limitation of AML PART-66.

The CAA-ZLP-121 AML PART-66 procedure [3], effective from 1 January 2020, replaces the existing CAA-ZLP-052 AML PART-66 [2] and modifies the rules for defining an aircraft maintenance technician license, setting requirements for application for this license, its issue and preservation of its validity. Among other things, it also defines a new approach to the procedure for the credits granting of theoretical exams of aircraft maintenance technicians based on achieved education.
The credits granting of theoretical exams from certain modules based on the achieved education is currently possible according to both specifying procedures [2, 3]. However, this is only in the transitional period until 30 June 2020. Starting from 1 July 2020, it is possible to apply for credits only according to the procedure CAA-ZLP-121 AML PART-66 [3].

According to the procedure CAA-ZLP-052 AML PART-66 [2], credit can be granted from the following modules, if the above conditions are met:
- M1 (Mathematics) – to pass an exam from the subject of mathematics in one year at high school;
- M2 (Physics) – to pass an exam from the subject of physics in one year at high school;
- M3 (Electrical Fundamentals) – to pass the high school-leaving examination in the subject of electrical engineering or to graduate at the mechanical or electrical engineering faculty;
- M4 (Electronic Fundamentals) – to graduate at the Faculty of Electrical Engineering;
- M8 (Basic Aerodynamics) – to own a pilot or flight engineer license or to pass an aerodynamics subject at a university.

According to the new procedure CAA-ZLP-121 AML PART-66 [3], credit can be granted only after proving the syllabus of the subjects from which the candidate requests the credits and these must cover the entire syllabus of theoretical knowledge from the modules. The list of modules from which credit can be granted is the same as for the old procedure [2].

Both procedures try to achieve the greatest possible agreement between the levels of knowledge of the subjects contained in the modules and the subjects that the applicant completed during the education. However, the endeavor is to tighten up these methods, as evidenced by the latest change in procedure.

The syllabuses of each module according to Regulation [1] take into account not only the syllabuses but also the levels. The level defines the depth of knowledge that each maintenance technician must achieve. Regulation [1] defines the following levels:
- level 1 – getting acquainted with the issue;
- level 2 – general knowledge of theoretical and practical aspects of the issue and the ability to apply them;
- level 3 – detailed knowledge of theoretical and practical aspects of the issue and the ability to logically use and combine them.

3. Procedure Proposal

This chapter describes the proposed procedure for the credits granting. The flow diagram of the whole procedure is shown in Fig. 1. The whole procedure begins with the submission of an electronic application for verification of the possibility of the credits granting through the website of the Civil Aviation Authority. In today's digital age, the electronic method of administration is very suitable. It is fast, reliable and secure. The electronic application should contain basic information about the applicant (name, place of permanent residence, date and place of birth, etc.). Additionally, the application should include a list of modules that the applicant wants to grant, scans of the required documents and internet links to the Framework Educational Program (FEP) and the School Educational Program (SEP) of the completed high school. If the credits granting have been done based on university education, the link to the Accreditation File (AF) of the graduated study program should be sent.

After analyzing the syllabuses of each module listed in the Commission Regulation (EU) No 1321/2014 [1], the modules that could be granted were chosen. The syllabuses of the chosen modules are focused on general knowledge of the issue and the conformity with the syllabuses of high or university education is significant. The credits from all chosen modules except M8 would be granted based on the certificates or diplomas from high schools or universities. The credit from M8 would be granted on presentation of a valid pilot's license. According to the original documents of the CAA [2], it was possible to grant the credit from M8 based on passing the university subject that was about aerodynamics. After studying the M8 syllabus in the Regulation [1], it was decided that the M8 will not be granted based on the passing the aeronautics subject on the university. The decision has been done due to the high specificity of the Regulation syllabus that is related to the aviation and due to a low probability that the points of the syllabuses in the Regulation [1] and in the study program AF are the same. Modules that can be granted are:
- M1 (Mathematics);
- M2 (Physics);
- M3 (Electrical Fundamentals);
- M4 (Electronic Fundamentals);
- M8 (Basic Aerodynamics).

The documents required for the credits granting procedure should be graduation certificates and year certificates from all grades in which subjects tied to the modules from which the credit should be granted were taught. In the case of a university, it is a diploma and a diploma appendix where all completed courses and subjects are listed. FEP, SEP and possibly AF are used to verify that the syllabuses of the subjects and their levels are in accordance with the requirements of the Regulation [1].

The second step is processing the application. The authorized employee would accept the application and check all data and the attached documents. At that point, the data from the database of high schools and universities enter the system. The database should contain at least the name of the school, the name and code of the study field, a list of modules for which it fulfils the syllabuses and levels given by the Regulation [1], a list of subjects in which the required
knowledge must be achieved and references to FEP, SEP or AF.

In case that the school or university is not included in the database, the CAA employee will add it to the database. The FEP, SEP or AF sent by the applicant serves to this purpose. In each of these documents, the syllabuses of the subjects are written and there are also verbal descriptions of what level students should reach. This fact was verified by the authors through the data and information given in references [4] and [6]. It was found out that the verbal descriptions of the levels in the FEP and other documents at most technical schools, from which most applicants for aircraft maintenance licenses come, correspond to level 2 as defined in the Regulation [1]. In some cases, it corresponds to level 3. The CAA states in its documents [3] that the syllabuses of one subject don't have to be identical with the requirements of the Regulation [1]. The problem can be solved that it will be required to pass more subject to grant the module. For example, the M1 will be granted not only based on passing the mathematic subjects but also informatics where the remaining points of the syllabus, which are not included in the subject of mathematics, are contained. In general, the granting of a single study module may require the passing of several different subjects in high school or university. These subjects will be determined by the CAA employee based on the analysis of FEP, SEP or AF. The school database would be gradually supplemented and if the applicant's school were already in the database, the CAA employee would only verify which modules can be granted.

The next step is to verify whether the pilot's license was submitted with the application. If so, M8 would be granted. If not, M8 would not be granted. Subsequently, a list of granted modules will be created. The condition for the modules granting is the achievement of the required knowledge confirmed by the mark "excellent" (1.0) or "commendable" (2.0) at high school in all subjects that come under the module. At university, the applicant must reach marks "A" (1.0), "B" (1.5) or "C" (2.0). The authors verified the percentage of knowledge that must be achieved to gain the above-mentioned marks. Regulation [1] requires to have minimally 75% for passing the exam (to gain the module). It was found out that obtaining the above marks approximately corresponds to the condition of 75% [5]. Respectively in some cases, the mark "commendable" or "C" corresponds to 70%. Given the fact that the subjects at high schools or universities in many aspects exceed the requirements of the Regulation [1], it is acceptable to tolerate this 5%
difference.

Based on the list of granting modules, an announcement on the application would be sent to the applicant. The announcement would contain information on which modules can be granted together with a request for delivering of officially certified copies of all necessary documents (certificate, pilot license, etc.). Upon delivery of these documents, the applicant would obtain the certificate of possible credits granting. The document would contain, among other things, the list of modules from which the credit can be granted.

The application for verification of the possibility of the credits granting should be submitted at least 30 days before submitting the application of the aircraft maintenance technician license. The license application should then be accompanied by the certificate of the possible credits granting.

4. Software for Procedure

To make effective use of the proposed procedure, it would be appropriate to develop a software – a web application, which would be managed for each EU country by the locally competent aviation authority. In other words, aviation authorities would obtain a tool by which they could grant the credits at clearly defined conditions. The contractor of such software should be the EASA, which would not only gain the unification of procedure within the EU, but would also gain an effective tool for monitoring the credits granting in the member states. This information would be indispensable for possible changes in the education of new aircraft maintenance technicians but also a tool for a quality management system throughout the EU. If it was a web application, it would be appropriate to extend it with the self-authentication part. Each aircraft maintenance technician applicant will fill in and upload the relevant documents himself/herself and in case of a match with the database, they would know the result of the possible credits granting. An authorized employee of the aviation authority would then only check the correctness of the documents and could grant credit without a lengthy study of the syllabuses.

5. Discussion

The proposed procedure is similar to both methods of the credits granting that have been or are used in the Czech Republic. The main difference compared to the procedures used by the CAA is taking into account the both – the given syllabuses and the levels defined by the Regulation [1]. The procedure also takes into account the fact that the syllabuses are given by the Regulation [1] and the FEP or other documents do not have to be 100% identical and proposes a solution in the form of taking into account more subjects in the credits granting. The second difference is the creation of a database of schools. There will be higher time requirements for CAA staff at the beginning of the proposed procedure but after filling the database the whole procedure will be speeded up and simplified. If the procedure proposed by the authors was used, it would be necessary to consult everything with the EASA and the whole system would have to be approved by the EASA.

6. Conclusions

The main aim of the article was to design a possible procedure of credits granting in accordance with PART 66. The proposed procedure should facilitate and unify the credits granting procedure within the EU. Simultaneously, the procedure is proposed so that it can be acceptable by both affected parties (aviation authority and applicant for credits) provided that the conditions of the regulations are met. The current credits granting procedure is correct and try to keep the safety [7] levels as high as possible. As a result, however, there could be a significant reduction in the number of granting credits. However, the authors believe that the EU education is at such a high level that fulfil the requirements of the Regulation [1], and therefore it is possible to use this situation and facilitate the procedure of obtaining the license of aircraft maintenance technician.

References

2. CZECH REPUBLIC. Postup pro AML PART 66. CZE: CAA, 2016, CAA-ZLP-052
Standardization of Selected Interfaces of Railway Traffic Control Equipment and Systems – Aspects of Cyber Security and Transmission Safety

L. Sokolowska

Railway Institute, Railway Traffic Control and Telecom Unit 50, J Chłopickiego Street, 04-275 Warsaw, Poland, E-mail: lsokolowska@ikolej.pl

Abstract

The paper presents the results of the first stage of the project under the name “Standardization of selected interfaces of railway traffic control equipment and systems” POIR.04.01.01-00-0005/17, was created as part of the BRIK (Research and Development in Railway Infrastructure) joint initiative and co-financing by The National Centre for Research and Development and PKP Polskie Linie Kolejowe S.A. (Polish Infrastructure Manager).

One of the results of the first stage is the specification of safety requirements for data transmission and cybersecurity in terms of the digital interface. The analyzes were based on the analysis of transmission system threats, the architecture of control systems, available transmission safety standards in terms of railways, and safety requirements for rail traffic control systems. The analyzes included the identification of rail traffic control systems in terms of cyber protection for defined security areas. The requirements include the ISO OSI model (International Standard ISO/IEC 7498-1:1994, Information technology – Open Systems Interconnection – Basic Reference Model: The Basic Model.) adapted to the conditions of railway systems.

KEY WORDS: control command systems, digital interfaces, safety data transmission, standardization of interfaces, cybersecurity, data safety, transmission standard

1. Introduction

In recent years, in rail traffic control systems, regardless of issues related to safety requirements for data transmission, cybersecurity issues are becoming increasingly important. Systems used on railways are no exception in this respect, although rail transport is not one of the areas most at risk of cybercrime or cyber terrorism. Challenges related to cybercrime require a systematic approach. One of the challenges is to provide comprehensive protection along with a sufficiently high level of cyber protection. In other words, one of the most serious threats is the insecurity or insufficient protection of some data and / or processes for collecting, storing, processing, exchanging and sharing data that has security implications, including in particular data related to rail traffic control.

Therefore, in the process of standardizing the interfaces of devices and rail traffic control systems, it is very important to identify the safety conditions of data exchange between various devices and rail traffic control systems. Because it allows us to collect and pre-organize basic requirements in the field of data transmission safety and cyber protection in rail traffic control systems.

2. Requirements for Transmission Safety by PN-EN 50159 and PN-EN 50129

Data transmission in the control of railway automation devices requires the exchange safety of information. The connection for the transmission of messages between interfaces in the railway automation system must be made in such a way that it is possible to detect errors in the telegram as soon as possible. However, a break in the transmission channel must cause a transition to a "safe state", according to the procedure determined individually for each type of system. In order to ensure the correct operation of the railway automation system, measures should be taken to prevent loss or distortion of the message, which may be the result of interference or unauthorized operation of other people. The open transmission system used in the system between interfaces, using public radio networks, should ensure the current level of safety in accordance with SIL (Safety Integrity Level) classification, resulting from the series standards: PN-EN 5012x and not worse than the level of safety in existing systems.

2.1. The Structure of the Safety-Related Data Transmissions System

If the interface includes the transfer of information between different locations, the transmission system is an integral part of the safety-related interface and end-to-end communication must be safe in accordance with PN-EN 50129: 2019-01. Safety requirements depend on the characteristics of the transmission system, which is why transmission systems are classified into three categories [2, 10, 12]:
2.2. Threats to the Transmission System and Classification of Transmission Systems

The main threat to a safety-related transmission system is failure that fails to obtain a valid telegram at the end of the receipt in terms of authentication, integrity, sequence and time regimes. However, it must protect against intentional and accidental misuse from authorized sources. Changes in transmission link performance may cause threats to telegrams transmitted by the control and protection system, they may occur either under normal conditions (i.e. without failure) or under special conditions (i.e. in case of transmission system failure). According to the PN-EN 50159: 2011 standard, a set of threats can be determined by threat tree analysis by dividing the analysis into three levels:

- user level (system / user) - e.g. deletion;
- network level (logical structure of the telegram) - e.g. all possible codes, sequence numbers, time stamps, etc.;
- the level of the external environment (physical level) - e.g. shielding to avoid data failure due to electromagnetic interference.

Dividing the analysis into different levels also provides the ability to apply security on (at least) three levels.

In order to classify all transmission systems, it is required to specify the process of identifying the threats relevant to them that affect the selection of safeguards included in the security application. Where the traffic control system uses transmission services provided by private or public telecommunications service providers, the liability of the service provider may be limited. Therefore, the importance of the threats (and thus the security requirements) depends on the size of the user's control over the transmission system. In this case, consider the following [2]:

- technical properties of the system, such as levels of system reliability and availability, size of data memory built into the system;
- invariably system performance during its lifetime and effects of traffic load by other users;
- access to the system, depending on whether the network is private or public, the scale of access control enforced by the operator on other users, the possibility of improper use of the system by other users, and the scale of access for maintenance personnel to reconfigure the system or gain access to the transmission medium itself.

2.3. Guidelines for Applying the Standard

In the process of designing the tele-transmission system between interfaces, can define the order of separate stages specified in the PN-EN 50129 standard. These stages are set out below [2]:

- Stage: Application - The system designer should understand the transmission system application, which should cover the overall goal of system safety;
- Stage: Threat analysis - A qualitative threat analysis in the system should indicate the main threats that may result from fault to the transmitting or receiving devices, or fault to the transmission links themselves. This analysis should take into account operational or other external conditions under which the system may be exposed to threats;
- Stage: Risk reduction - Based on the overall quantitative safety goal for the system and qualitative threat analysis, the system designer can assign safety goals for each identified threat. By using quantitative threat information, it is possible to specify the scale of risk reduction required for each type of defense;
- Stage: Assigning the SIL level and defining quantitative goals - Depending on the scale of risk reduction
required for each defense method, the SIL level can be assigned using procedures defined in PN-EN 50129. Knowing the SIL level for a given defense method, it can be choosing the right design techniques. Based on the quantitative indicator of dangerous failure specified for a given method of defense, it can be choosing the right techniques for designing the equipment and calculate the indicator of the occurrence of dangerous failure for randomly occurring defects;

- Stage: Safety Requirements Specification SRS - Safety measures identified as necessary to ensure the safe operation of the system, SIL levels for the implementation of these safety measures, and quantitative safety goals for the system should be noted in the SRS for a given system.

2.4. Safety Requirements and Safety Integrity of Systems and Interfaces

The specific safety requirements for each system/interface are:
- functional safety requirements - required real safety-related function performed by the system/interface;
- safety integrity requirements - specify the required level of safety integrity for each safety-related function, should be identified and documented in the safety requirements specification.

Safety integrity is combined with the ability of a safety-related system to perform the safety functions, that are required of it. The greater the safety integrity the less probability, it will fail to perform its required safety functions. The safety integrity is defined as one of four levels. Level 4 has the highest safety integrity level, level 1 has the lowest. Level 0 means there are no safety requirements. It is recommended that the safety integrity level SIL indicates a qualitative assessment of factors such as quality and safety management and technical safety conditions. System-related threats are identified and assessed for their potential effects during the risk analysis phase of the system's life cycle. The results of this action are the tolerated coefficients of threat for each threat. During the next phases, the system requirements phase and the phases of requirements separation for the system, the tolerance threat factors are divided into system and subsystem functions, respectively. Each of these functions should have a qualitative safety goal and a quantitative goal associated with it. The quality goal should be in the form of a safety integrity level and should include the integrity of systematic failure. The quantitative goal should be in the form of a numerical value of the failure index and should include the integrity of random failure.

Achievement of the specified safety integrity level requires compliance with all of the following factors (Fig. 2):
- quality management conditions;
- safety management conditions;
- technical safety conditions;
- quantitative safety goals.

Fulfillment of a given quantitative safety goal does not therefore mean that the corresponding safety integrity level has been achieved. Similarly, meeting the conditions of quality management, safety management and technical safety related to a given safety integrity level does not mean that the corresponding quantitative safety goal or safety integrity level has been achieved. In order to achieve specified safety integrity, it is necessary that all the factors of Figure 2 are met.

It is assumed that safety involves both the use of appropriate measures to avoid or tolerate defects (such as protection against systematic failure) and the use of appropriate measures to control random failure. It is recommended that measures against both causes of failure be balanced in order to achieve optimal system safety properties. To achieve this, the Safety Integrity Level (SIL) concept is used. SIL levels are used to adapt a qualitative approach (to avoid systematic failures) to a quantitative approach (to control random failures) because quantifying systematic failures is not feasible.
3. The Scale of the Challenge Regarding Cyber Threats

Railway transport cannot be considered free of cyber threats. This is evidenced in particular by the data provided by the International Union of Railways UIC. The following is a list of cyber-attacks identified in different types of transport (Fig. 3), on the one hand, shows the global rise of threats (orange line), on the other, in practice, the same order of magnitude of threat regardless of the type of transport (red line - aviation, green - highways, gray - military transport, yellow - sea transport, blue - rail transport) [1].

3.1. Identification of Safety Systems Subject to Cyber-Threats

The following systems and devices have been identified that affect safety which use: collection, storage, processing and transmission of safety-relevant data:
- classic rail traffic control systems, including in particular: station locking, section blocks and automatic level crossing protection systems;
- timing control systems, including associated systems;
- safe-train driving control systems, including in particular: automatic train driving supervision systems, including associated systems;
- railway automation systems, including in particular: railway clocks, passenger information systems and broadcasting systems;
- CCTV systems used to support mobile personnel, for example finding out the end of a train;
- systems and devices for detecting failures and informing personnel about failures and incorrect functioning of systems and devices, in particular rolling stock systems and devices, including in particular: diagnostic and monitoring systems.

3.2. The Scope of Cybersecurity Protection

Since the eighties of the last century, started use the safety systems active (interlocking, interlocks, automatic level crossing protection systems) based on programmable electronic solutions using computer techniques have been started on the railways. The implementation of such solutions required the definition of requirements, the fulfillment of which would allow acceptance of individual technical solutions in the context of security. It is not possible to verify the application of the fail-safe principle in the full range of possible failures. Therefore, safety integrity levels and requirements for secure communications systems have been defined. Railway traffic control systems and devices, including safe driving control systems, must use solutions that minimize risk to SIL-4 safety integrity. The rules used in this area are defined in the RAMS Standards [2-7, 11], the application of which is imposed by both European law [8] and Polish law [9]. Therefore, the safety areas and cybersecurity requirements have been defined:
- cybersecurity requirements have long been set for devices and systems (for control systems, the law requires full consideration of cybersecurity);
- cybersecurity requirements have long been set for devices and systems of specific types (the requirement to ensure cybersecurity of devices and control systems is transferred to selected substantive areas of technical safety - failure safety or traffic regulations, but only in relation to rail traffic control systems and devices).

Areas have also been identified in which the law does not require protection against cyber-attacks, but in which entities responsible for railway transport increasingly demand such requirements. This applies in particular to technical solutions used in the field of protection against access and fire and prevention of panic in connection with the protection of life, health and property, i.e. areas in which:
- awarding entities recognize the need to ensure cybersecurity, but they have neither general requirements regarding the need to provide cybersecurity, nor any guidelines for assessing the adequacy of such security;

In railway transport, technically advanced solutions based on data transmission are also used in other areas. In
particular, this applies to information systems for travelers before and during a journey, ticket sales systems, as well as systems that directly affect the organization of traffic, such as systems for scheduling and booking train routes - an area where:

- until recently, cybersecurity issues were completely outside the scope of the discussion on cybersecurity on railways, and are now included, but not at the level of railways, but rather at the level of cybersecurity discussions on the scale of state transport systems.

The selection of appropriate security requires defining the system’s tasks and describing the proposed technical solutions in a way that will allow full identification of threats. Dangerous events against which transmission systems are protected include systematic failures (occurring as a result of human errors, such as incorrect wiring installation, incorrect antenna alignment, ...), random failures (such as e.g. hardware failure, aging materials, electromagnetic interference, etc ...) and intentional actions (for example, the installation of wiretaps, damage or unauthorized substitution of hardware components, unauthorized software changes, etc.).

![Layers ISO/OSI](image)

Today, virtually all types of data processing systems communicate with external systems. For the purposes of such data exchange, the reference system of Open Systems Interconnections (OSI) has been defined. This model has been jointly defined by various standardization organizations (global ISO and IEC as well as European CEN and CENELEC) and is widely used. The OSI model defines connections between open systems, i.e. those using so-called gateways, using four lower layers: physical, data links, network and transport, and three higher layers: sessions, presentations and applications (Fig. 4).

Threat analysis and defining security for traffic control systems and safe driving control cover all layers.

4. Conclusions

For a long time, it was considered that the systems used for railway traffic safety should be fully separated. It was assumed that one of the guarantors of safety is to ensure the closed nature and individual characteristics of the transmission system. This assumption is not true for years. Currently, closed systems are increasingly used only at the level of defining the group of senders and recipients who are subject to authentication.

For control systems and safe driving control systems, in accordance with the already quoted RAMS standards [2-7], safety cases are created for individual applications, taking full account of the transmission systems used. Starting from June 2019, the provisions of European law introduce the obligation to use this type of analysis also for: infrastructure, energy and rolling stock subsystems based on the new two-part RAMS standard EN 50126 series [5-6]. Guidelines for security and cyber security of data transmission for interfaces proposed in [1] were adopted by PKP PLK S.A.

References

1. Research and development project “Standardization of selected computer interfaces of devices and railway traffic control systems” - “Transmission safety and cybersecurity elements” No. POIR.04.01.00-00-0005/17, Warsaw 2019.
2. PN-EN 50159:2011 „Zastosowania kolejowe. Systemy łączności, sterowania ruchem i przetwarzania danych. Lączność bezpieczna w systemach bezpiecznych”.
4. PN-EN 50126:2002 Zastosowania kolejowe – Specyfikacja niezawodności, dostępności, podatności utrzymaniiowej i bezpieczeństwa
5. PN-EN 50126-1:2018-02 Zastosowania kolejowe – Specyfikowanie i wykazywanie niezawodności, dostępności, podatności utrzymaniiowej oraz bezpieczeństwa (RAMS) – Część 1: Proces ogólny RAMS
6. PN-EN 50126-2:2018-02 Zastosowania kolejowe – Specyfikowanie i wykazywanie niezawodności, dostępności, podatności utrzymaniiowej oraz bezpieczeństwa (RAMS) – Część 2: Sposoby podejścia do bezpieczeństwa
7. PN-EN 50128:2011 Zastosowania kolejowe – Systemy łączności, przetwarzania danych i sterowania ruchem –
Oprogramowanie kolejowych systemów sterowania i zabezpieczenia

8. Rozporządzenie Komisji (UE) nr 2016/919 z dnia 27 maja 2016 r. w sprawie technicznej specyfikacji interoperacyjności w zakresie podsystemów „Sterowanie” systemu kolei w Unii Europejskiej (Dz.U.EUE.L.2016.158.1)

9. Lista Prezesa Urzędu Transportu Kolejowego w sprawie właściwych krajowych specyfikacji technicznych i dokumentów normalizacyjnych, których zastosowanie umożliwia spełnienie zasadniczych wymagań dotyczących interoperacyjności systemu kolei z dnia 19 stycznia 2017 r.


The Choice Restriction Model of the Mean of Transport due to the Route Capacity

P. Purkart¹, J. Kruntorád², T. Javořík³, L. Týfa⁴

¹CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail: purkapav@fd.cvut.cz
²CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail: kruntjan@fd.cvut.cz
³CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail: javorik@fd.cvut.cz
⁴CTU in Prague, Faculty of Transportation Sciences, Department of Transportation System, Konviktská 20, CZ 110 00 Praha, the Czech Republic, E-mail: tyfa@fd.cvut.cz

Abstract

Each transport route has a limited capacity; but in the case of railway transport, this characteristic is noticeable. This can lead to a situation where there are more requirements to be placed on the transport route than the route can deal with. This paper describes this issue and offers a possible solution for passenger transport. There may be situations where public transport orderers or carriers have requirements that the infrastructure cannot fully satisfy. By using the modified STEM method, it is possible to determine which requirements to comply with in the way that the capacity of the transport route is utilized optimally with maximum benefits. The example is demonstrated in the real part of the railway infrastructure between Plzeň and Žatec in the Czech Republic.

KEY WORDS: railway infrastructure capacity, requirements of carriers and orderers, STEM method, Plzeň – Žatec railway line, optimization

1. Introduction

The capacity of the railway infrastructure is a parameter that influences its usability. Not only in the Czech Republic, but in all developed countries, where rail transport is used as the backbone of transport services in regions, its capacity is a major problem, often failing to meet all requirements. This raises the question of how to realize the operation of trains so that this is as effective as possible with regard to the constraining infrastructure [1, 2]. There are no uniform procedures and practically every infrastructure manager solves this issue differently.

This issue is also addressed by CTU in Prague, Faculty of Transportation Sciences, Department of Transportation Systems, which encounters this complication not only in scientific work, but also in solving practical studies for various subjects. To solve the problem, the STEM (Step Method) method is currently being considered and tested.

2. Using the STEM Method

The STEM method can solve linear mathematical problems with more purpose functions. The aim of this method is to find compromise solutions, whose realizations should bring the most benefits. The main principle of the method is the calculation of purpose function ideal values for individual cases. This calculation is followed by minimizing compromise solution deviation from ideal purpose function values. The basis of the method is an interactive procedure of searching the compromise solution.

The benefit of the STEM method is, that there is only minimal need for communication between a submitter and a solver (comparing to other methods). The scale method for individual criteria is set by calculation. The submitter must decide whether the result of the calculation is acceptable for him or not. So, the method consists of the calculation and decision-making process. The calculation is stopped, if the submitter finds the result acceptable, otherwise the solver must be informed by the submitter to change the criteria or their numbers, the whole calculation is made again.

The STEM method consists of the following steps [4]:

1. The solver calculates optimal solutions for individual criteria (purpose function) separately. The number of calculations fits the number of criteria.
2. The solver calculates the scales of individual criteria according to the formula (1):
\[
   w_j = \frac{z_{ij} - \min_{i=1,j,k} z_{ij}^*}{z_{ij} - \left( \frac{\alpha}{\sum_{j=1}^{k} c_{ij}^2} \right)},
\]

where \(z_{ij}\) – element of optimization criterions values matrix for optimization in individual optimization criterion \((z_{ij}^*\) is the value of optimization criterion \(j = 1,...,k\) in case of optimization according to the criterion \(i = 1,...,k\)) \(c\) – the element of the price matrix – the element of individual optimization criterion coefficients matrix.

Value \(\alpha\) comes from Eq. (2):

\[
   \frac{z - \min z}{z} \frac{\alpha}{\sqrt{c}} = 1.
\]

In reality, we have to calculate the coefficient \(\alpha\) value first and then count the scales of individual criteria. If the scale fits the constraint \(w_j \geq 0\) for more criteria, the solver adds a new variable \(d \geq 0\) and solves the model with a new optimization criterion (3).

\[
   \min f(x,d) = d.
\]

There is a form (4) for variable \(d\):

\[
   d = \max_{i=1,j,k} \left\{ w_i \left( z_{ii} - \sum_{j=1}^{k} c_{ij} X_j \right) \right\}.
\]

We have to implement constraint (5) for correct calculation:

\[
   w_i \left( z_{ii} - \sum_{j=1}^{k} c_{ij} X_j \right) \leq d.
\]

If the constraint \(w_i > 0\) fits for only one value \(i = 1,...,k\), the solver can simplify the constraint (5) to (6):

\[
   \min f(x) = \sum_{i=1}^{k} w_i \left( z_{ii} - \sum_{j=1}^{k} c_{ij} X_j \right).
\]

3. The solver presents the results to the submitter. The submitter must modify the criteria or add/remove some of them, if he does not find the results acceptable. The solver goes back to step 2. The solver has found a compromise solution, if the submitter is satisfied with the result. The solution is optimal, if the value \(d = 0\) is reached.

3. Modifying the Model and Specific Use

The evaluation criteria for individual lines were established for the modified STEM method as follows [3]:

**The daily estimated average number of passengers in the limiting railway section in thousands**

The parameter expresses the daily average number of passengers on the route in the limiting section, so in the section with the lowest capacity. The value expresses the passenger numbers of trains on the given line in this section.

**The daily estimated average number of passengers on the whole route of the line in thousands**

The parameter expresses the daily average number of passengers on the whole route of the line, respectively on the logically limited section of the line. This parameter provides an evaluation of the total line utilization. It is not sufficient to consider the potential only on the limiting section mentioned above, but it is also crucial to assess the potential of the whole line.

**The use of critical running speed in a logically limited railway section**

Often there are cases where trains run at a slower speed without being able to use the full line parameters. It is the reason why implement this parameter. When the train can develop speed in the limiting section of the railway line according to the critical running speed specified for the line profile, the ratio will be 1 (100%). If this is not achieved, the ratio will decrease. If the line speed is up to 100 km/h on the track in the limiting section and the train is able to develop a maximum speed of only 80 km h, the ratio will logically decrease to 0.8 (80%).

**Evaluation of system connection links on the line in a logically defined section**

The parameter is set for evaluation of links to other lines, the aim is to determine the importance of the network character of the line. The overall rating of the parameters is the sum of the following points for all interchanges in the
logically delimited section of the line. The transfer nodes/points are evaluated as follows:

2 points – railway interchange with system connections to lines in at least three other lines of rail transport
directions (at least a crossroad stations, but rather nodal stations) with the possibility of system links to public regular
bus transport or city public transport;

1 point – a railway interchange point with system links to lines in at least one or two other directions within the
scope of railway transport with the possibility of system links also to public regular bus transport or city public
transport; there can be the only system links public regular bus transport or city public transport.

If a line is routed through an important interchange, it receives 2 points for that interchange. It receives 1 point
for each interchange point (that is a lower priority interchange). The higher the sum of points, the more frequent and
important the links are, and therefore the operation of the line is crucial for the efficient functioning of other public
transport lines.

Comparison of travel times of individual car transport and each line in the three most by passengers used
routes on the line

The parameter is set to compare the competitiveness of the train line with individual car transport. In the
logically delimited section of the line, the three busiest sessions will be selected and the ratio of the travel time of
individual automobile traffic in the given section to the travel time using the section of the given line will be
determined. For these sessions, the value will be determined separately and then the average of the three values that will
be included in the evaluation will be calculated. It follows from the above that if the value exceeds number 1, public
transport is on average in a selected session faster than individual car transport.

The Plzeň - Žatec line was chosen for the model test. The line runs from the regional city of Plzeň (Pilsen) in the
western part of the Czech Republic to the agglomeration in the Podkrušnohorská pánev in the northern part of the
country (cities of Žatec, Chomutov, Most and Jirkov). Especially in the Pilsen agglomeration, the capacity of the
railway infrastructure on this line is very restrictive, therefore it was chosen as a test. The STEM method has been
modified from the original use primarily for project evaluation, providing evaluation and results for project selection
with limited financial possibilities. Newly, the capacity-limiting section of the railway infrastructure has been filled for
a given period of time, through which trains should pass such that the benefit for society is maximized.

It is considered that, on the line roughly in the current state of infrastructure, there will be a conflict in the
requirements of public transport orderers:

- line R (fast train) Plzeň – Most in 120 minute interval;
- line Sp (regional fast train) Plzeň – Žihle in 120 minute interval;
- line Os no. 1 (regional train no. 1) Plzeň – Žihle in 60 minute interval;
- line Os no. 2 (regional train no. 2) Nýřany – Plzeň – Plasy in 60 minute interval.

This line schema ensures the total interval of the last segment of trains in the section Plzeň – Žihle in 60 minutes
and in the case of regional trains the total interval of 30 minutes of regional trains in the peak period.

Given the fact that the basic interval of the most sparsely represented train segments is 120 minutes, this value
was also chosen as the starting point for determining the length of the evaluation period. We consider even traffic in
both directions, so for each direction in this period the capacity of the track is available, including all operations
(disturbance and construction of train route, etc.) 60 minutes, if expressed by the number of minutes, not the number of
routes, as considered in the model. This value is reduced to 50 minutes in order not to reach the occupancy rate of 100
%. In this case, it is also considered that during peak periods, the operation of freight trains on this line is minimal, so
regular routes are not required for them, otherwise, this value would have to be reduced even more.

It follows from the train timetable diagram that the most fundamentally restrictive section is the Horní Bříza –
Kaznéjov section [Error! Reference source not found.]. This section is considered for the calculation, with the
following occupancy time for individual lines:

- line R 8 minutes;
- line Sp 9 minutes;
- line Os 10 minutes.

Daily estimated average number of passengers in the limiting railway section in thousands

The estimated number of passengers in the limiting section (Horní Bříza – Kaznéjov) and on the whole route of
lines were estimated from the experience of the current operation, as the following values in thousand passengers per
day (Table).

<table>
<thead>
<tr>
<th>Line</th>
<th>Numbers of passengers in the limiting railway section</th>
<th>Number of passengers on the whole route of the line</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0,9</td>
<td>1,4</td>
</tr>
<tr>
<td>Sp</td>
<td>0,8</td>
<td>0,9</td>
</tr>
<tr>
<td>Os no. 1</td>
<td>0,5</td>
<td>1,5</td>
</tr>
<tr>
<td>Os no. 2</td>
<td>0,3</td>
<td>2,5</td>
</tr>
</tbody>
</table>

Table 1

Number of passengers of model lines [in thousand passengers per 24 hours]
The use of critical running speed in a logically limited railway section

For the use of critical running speed, the determined parameters are set in Table 2.
In the case of all connections, the full use of critical running speed is planned.

Evaluation of system connection links on the line in a logically defined section

The individual lines serve the nodes below. The evaluation of individual nodes from the point of view of their significance is summarized in Table 3.

<table>
<thead>
<tr>
<th>Line</th>
<th>The use of critical running speed in a logically limited railway section</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>1.00</td>
</tr>
<tr>
<td>Sp</td>
<td>1.00</td>
</tr>
<tr>
<td>Os no. 1</td>
<td>2 x 1.00 = 2.00 *</td>
</tr>
<tr>
<td>Os no. 2</td>
<td>2 x 1.00 = 2.00 *</td>
</tr>
</tbody>
</table>

For regional trains, the value is multiplied by two, as two trains pass in each direction over a reference period of 120 minutes.

<table>
<thead>
<tr>
<th>Line</th>
<th>Evaluation of system connection links of model lines in individual nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nýřany</td>
<td>Plzeň – Jižní P.</td>
</tr>
<tr>
<td>R</td>
<td>-</td>
</tr>
<tr>
<td>Sp</td>
<td>-</td>
</tr>
<tr>
<td>Os no. 1</td>
<td>-</td>
</tr>
<tr>
<td>Os no. 2</td>
<td>1</td>
</tr>
</tbody>
</table>

The values for the individual lines are summed into the model as a whole, and the accumulation of these values is expressed in Table 4. For experimental reasons, the values of the lines that pass through the section twice during the evaluation interval are not multiplied twice.

<table>
<thead>
<tr>
<th>Line</th>
<th>Cumulative evaluation of system connection links of model lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>11</td>
</tr>
<tr>
<td>Sp</td>
<td>7</td>
</tr>
<tr>
<td>Os no. 1</td>
<td>9</td>
</tr>
<tr>
<td>Os no. 2</td>
<td>10</td>
</tr>
</tbody>
</table>

Comparison of travel times of individual car transport and each line in the three most by passengers used routes on the line

The values of the ratio of travel time of individual car transport and trains of the given lines were determined for individual lines from the averages of the following important routes:
- R: Plzeň – Mostecko, Plzeň – Plasy, Plzeň – Žihle;
- Sp: Plzeň – Kaznějov, Plzeň – Plasy, Plzeň – Žihle;
- Os no. 1: Plzeň – Horní Bříza, Plzeň – Plasy, Plzeň – Žihle;

The results are summarized in Table 5.
Table 5

<table>
<thead>
<tr>
<th>Line</th>
<th>Comparison of travel times of individual car transport and each line in the three most by passengers used routes on the line</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0,80</td>
</tr>
<tr>
<td>Sp</td>
<td>0,87</td>
</tr>
<tr>
<td>Os no. 1</td>
<td>0,80</td>
</tr>
<tr>
<td>Os no. 2</td>
<td>0,87</td>
</tr>
</tbody>
</table>

For these criteria, the model was compiled according to the principles given in chapters 2 and 3 and entered into Xpress (input source code and generated outputs - see Fig. 1).

4. Conclusion

Linear optimization was performed with the result that lines R (fast train), Os no. 1 (regional train no. 1) and Os no. 2 (regional train no. 2) should be operated on the railway infrastructure. This combination seems to be the most effective according to the STEM method. The value of the coefficient \( d \) reached 0.167, which means that a compromise solution was found, not a global optimum. In terms of traffic on this line, the result achieved by the model is logical. For the number of passengers transported in all operating sections of these lines, the global optimum has been reached, because these are cumulatively the lines with the highest expected numbers of passengers. However, it is evident the model's complexity, because the line Sp (regional fast train) has been eliminated, which in the limiting railway section has the second highest expected number of passengers out of all four lines. It is clear from this case that a compromise solution has been reached overall.

The above form of research shows that the STEM method can be modified not only for the problem of railway infrastructure capacity, but also for solving other tasks by the computational way. In the above task, the method achieves relatively satisfactory results, but it will be the next mission of the research team to test other methods and...
compare the results achieved by them. So far, the STEM method has been used intensively. However, the evaluation criteria must be chosen carefully and responsibly, otherwise, the method will not give satisfactory results. However, if this is done, it may be an appropriate tool for deciding or assessing situations that are optimal or possibly suboptimal solutions is not obvious.

Acknowledgment

All the facts presented in this article are based on the results of the research on the CTU Faculty of Transportation Sciences, Department of Transport Systems. This research was supported by the Grant Agency of the Czech Technical University in Praha, grant No. SGS18/150/OHK2/2T/16 Railway track parameters for transportation service optimization and No. SGS20/138/OHK2/2T/16 Design and optimal use of railway infrastructure parameters.

References

5. Public available operational documents (timetables etc.) of Správa železnic, state organization (Czech state railway infrastructure manager
Creation of Aton’s Network on Critical Sections of the Dnieper River

I. Gladkykh¹, A. Raynov², J. Oleynik³, V. Shepel⁴

¹National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: gladkykh958@gmail.com
²National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: raynovaleksandr@gmail.com
³National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: j0633590714@gmail.com
⁴National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: victoriya.shepel@gmail.com

Abstract

As part of the implementation of the E-40 project of the pan-European shipping route, a project is being developed at the critical sections of the Dnieper River to install a modern AIS Aids to Navigation (AtoNs) Network, which allows remote monitoring of aids to navigation, determine the position of the water level and, accordingly, the fairway, and relay the position of virtual buoys on AIS communication channels. The article shows examples of calculations to determine the optimal location of AtoNs AIS for their effective use.

KEY WORDS: AtoNs AIS, monitoring

1. Introduction

Inland Water Transport (IWT) is the cheapest mode of transport nowadays, consequently should be efficient. It depends on many factors, the most important of which is safety. The development and implementation of new modern technologies in IWT will increase the level of security, as to ensure it on 100% is impossible for a number of reasons. The paper presents the materials of analytical and experimental studies, which are designed to develop the concept of updating and creating AtoNs Network on difficult areas of the Dnieper, using modern technologies. The work is carried out as part of the E40 waterway construction project and the European project “Dnieper Transport Development”.

Existing AtoNs Network on the Dnieper River does not pass modern requirements with the current value of information content, economy and in some cases safety. Therefore, options for improving these parameters should be considered, starting from an analytical review, at first glance the simplest constructions virtual aids.

The purpose of the Virtual AtoN System is to provide a near-instantaneous warning to the mariner of a new danger, such as a wreck, obstruction or floating debris. This warning must be provided in a form that can be received, interpreted and displayed by any class of vessel in the required operational area and carrying appropriate equipment.

The ability to provide Virtual AtoNs could be one of the most significant technical developments for the General Lighthouse Authorities (GLA) in the medium term. This only becomes possible through the deployment of a network of AIS bases stations around the coast and the installation of onboard equipment with the capability of displaying the Virtual AtoN symbols [1-4].

2. Research

A Systems Engineering approach has been used in preparing the design and architecture for a GLA Virtual AtoN System. This involved assessing available information; requirements analysis; functional analysis; defining measures of effectiveness; identifying the essential elements and generating a model. A risk analysis has been performed using Failure Mode and Effect Analysis (FMEA) techniques.

Informing the user about the deployment and removal of Virtual AtoNs will be important for them to be fully effective. Informing the user if the Virtual AtoN has been discontinued before the removal of the wreck or obstacle will be crucial to safe navigation, whether that removal is intentional or because of a malfunction in the Virtual AtoN system. The method of promulgating this information and the time is taken to present it to the user is part of the risk analysis.

The criteria for rapidly marking wrecks and other new dangers relate to an assessment of the danger posed to shipping in the area. The criteria for the replacement of existing AtoN on virtual will involve an assessment of the navigational value of the physical characteristics. Typical locations would include deep water AtoN intended only for SOLAS Convention vessels. Possible future provisions for new vessel types such as Wing In Ground (WIG) craft arises from the need to mark a channel without having the physical obstruction of an AtoN. However, it remains to be seen whether there would be a long-term requirement for virtual AtoNs in these applications, once the electronic navigation chart had been updated. Another mode of application would be as “cats-eyes” marking the center or edges of the
channel, to guide vessels around an obstruction, or as part of a “Motorway of the Sea”.

The GLA has classified their areas of responsibility according to times to respond to wrecks and other incidents. Assuming a close correlation between shipping density and probability of collisions and wrecks, the same classification areas might apply to the provision of supporting infrastructure for Virtual AtoNs.

Display equipment installed onboard many ships at present, including ECDIS and radar, does not generally have the capability of displaying virtual AtoNs. However, current IEC specifications (IEC 62288 & 62388) for Navigation Displays and Radar, do in due a symbol for AIS AtoNs diamond centered on the position, with a V inside it to indicate Virtual AtoNs - as shown on Fig. 1.

![Fig. 1 Symbol for AIS AtoNs](image)

From a Human Element perspective, mariners not familiar with the application of virtual AtoN may be confused by the graphical presentation of AtoN which they are not able to physically see and it may be less confusing to move to the next logical step for the transmission of information concerning new dangers, such as wrecks, and instead of using virtual AtoN to develop a means of transmission of the graphical depiction of the actual danger or the provision of an area to be avoided.

Examples of the location of virtual AtoNs, which at the first stage have been combined with physical ones, shows on Fig. 2. It should be noted that during the research, the positions of these two images did not always coincide. It can be explained by the fact that on the map the image of the virtual buoy exactly corresponds to its coordinates, while the physical buoy for various reasons changed its position sometimes in a radius of 10 meters. In this case, navigators are recommended to focus on virtual AtoNs.

![Fig. 2 Location of virtual and physical buoys in the AIS area](image)

The entire navigable part of the Dnieper is covered by an AIS signal with overlapping, as well as VHF, but not in full volume, as shown in Fig. 3. Considering modern technologies, a network of AIS AtoN has been developed using VHF channels.

Direct data exchange via VHF AIS channels is possible within VHF radio communication approximately 30 nautical miles. Coastal stations of the vessel traffic management systems using VHF channels can monitor by the same range. In the situation of occurrence anomalous transmission of VHF radio waves through reflections from the ionospheric layers, when the communication range can reach several hundred nautical miles, this fact can’t be taken into account because of its irregular nature. To increase the monitoring range, for example, to control vessels in the exclusive economic zone or exclusive tanker zone, AIS equipment can be connected to long-distance radio systems.

The following systems belong to long-distance radio systems:
- Short-wave communication system;
- Satellite communication systems.
Fig. 3 Location and coverage area with an overlap of AIS base stations, VHF signal coverage areas

AIS onshore equipment operating in the UkrRIS system is designed to monitor vessels, assign in the area of responsibility essential operating modes of AIS class A, B and aids to navigation. AIS of all modifications have access
to VDL (VHF Data Link) using FATDMA (Fixed-access time division multiple access) and RATDMA (Random access time-division multiple access), which allows performing the following actions:
- remote power management;
- automatic switching to the backup power source while disappearing the main one and backward without interrupting the operation;
- remote monitoring of power supplies;
- remote software update.

The structural diagram of building a RIS network in Ukraine based on the use of AIS is shown in Fig. 4.

![Diagram of RIS network general structure in Ukraine](image)

**Fig. 4 RIS network general structure in Ukraine**

Server data collection and processing (Server DCP) information on the Dnieper is shown in Fig. 5.

![Diagram of Server DCP on the Dnieper River](image)

**Fig. 5 Server DCP on the Dnieper River**

Our observations showed that the AIS in its original format cannot provide sufficient accuracy for determining the coordinates of the vessel using AIS AtoN.

Therefore, it was proposed to eliminate this disadvantage to expand the area covered by the Control & Correction Station (CCS) for AtoN, which would allow determining the coordinates of the craft with an accuracy of 3 meters. The following is an algorithm for implementing the work of determining coordinates using AtoNs with correcting and displaying the craft on the ECDIS with accuracy by the requirements given in Table 1(1a).
### Table 1

<table>
<thead>
<tr>
<th>Application</th>
<th>Position Accuracy [m]</th>
<th>Integrity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland ECDIS</td>
<td>&lt; 5 (Absolut)</td>
<td>Detection of Errors &gt; 3 σ within 30 Seconds</td>
</tr>
<tr>
<td>Navigation</td>
<td>&lt; 5 (1 Sigma)</td>
<td></td>
</tr>
<tr>
<td>Inland AIS (Short-term ahead)</td>
<td>15-100</td>
<td>Note: Also, the requirements of the IMO Resolution A.915(22) regarding the integrity, availability and continuity for position accuracy on inland waterways shall be fulfilled.</td>
</tr>
</tbody>
</table>

### Table 1(a)

<table>
<thead>
<tr>
<th>Position accuracy [m]</th>
<th>Bridge collision warning</th>
<th>Automatic guidance</th>
<th>Mooring assistance</th>
<th>Conning display</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height accuracy [m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heading accuracy [°]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrity risk</td>
<td>10 10⁻⁵ / 2 min</td>
<td>3 10⁻⁵ / 3 h</td>
<td>0.55 10⁻⁵ / 3 h</td>
<td>18 10⁻⁵ / 1 h</td>
</tr>
<tr>
<td>Time to alarm [s]</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

Requirements are made on the following assumptions:
- Each point on a 185 m convoy shall be known with 30 cm accuracy;
- Integrity risk assumes, that one non detected error within three years can be tolerated.

The results of an experiment in the Ukrainian section of the river Danube using signals transmitted from AIS base stations installed in the ports of Ust-Dunaysk, Vilkovo, Kiliya, Izmail and Reni are shown in Fig. 6.

Signals from these stations were measured and calculated mean-square error of the vessel’s position on all points of the route using the CCS located on Snake Island.

![Fig. 6 Experimental measurements of the AIS signal level and calculated results of the mean-square error position of the vessel](image)

### 3. Conclusions

As a result of the research the following problems and objectives were established.
Problems:
1) There is no decision at the state level on the mandatory equipment of AIS vessels (at the approval stage);
2) Inadequate training of dispatching personnel in working with AIS;
3) Poor training of navigators on the maintenance of shipboard AIS;
4) Lack of support control over shipboard AIS by coastal services;
5) There is no full coverage of the amendments to the CCS AtoN, which does not allow obtaining necessary results.

Objectives:
1) Identification and elimination of “dead zones” on the waterway;
2) Expansion of coastal AIS network;
3) Increasing the transmission network of diff corrections using AIS using VHF;
4) Technical training and mastering by dispatch personnel of all the capabilities of AIS base stations;
5) Integration of AIS with a ship reporting system;
6) Full VHF communication coverage.

References
Waterborne Transport Contribution to the Lithuanian Marine and Near-Shore Pollution

D. Bagocius¹, L. Rimkiene-Kelpsaite², R. Faidusiene³, O. Anne⁴

¹Kaunas University of Technology, Vytauto g. 3, 44354, Kaunas, Lithuania, E-mail: donatas.bagocius@ktu.edu
²Klaipeda University, Herkaus Manto 84, 92294, Klaipeda, Lithuania, E-mail: loreta.kelpsaite@jmtc.ku.lt
³Klaipeda University, Herkaus Manto 84, 92294, Klaipeda, Lithuania, E-mail: r.faidusiene@gmail.com
⁴Klaipeda University, Herkaus Manto 84, 92294, Klaipeda, Lithuania, E-mail: olga.anne@ku.lt

Abstract

Marine regions have the historical attractiveness of exploitation of natural resources and access to trades using marine transport as well, opportunities for recreation and tourism. European maritime activities in general and Lithuanian in particular are the essential sectors of the economy and social life with an ever-increasing tendency for further development. The exploitation of marine resources leads to the appearance of anthropogenic pressures and requires ongoing preventive and protective actions against chemical physical and marine littering pollution. The following article discusses potential ways of marine and near-shore pollution resulting from shipping activities at Lithuanian marine waters that appear in the ways of littering and dispersal of its debris, introduction of noise energy. The role of the water body’s hydrological and climatic conditions having an influence on waste migration from the sea to the shore is demonstrated. The methods of presented research encompass an analysis of ships’ automatic identification system data, identification of the pollution’s accumulation points based on the CERC method is assessed [9], the analysis of underwater noise levels registered at Lithuanian marine areas is completed. The analysis of the legal EU regulations along with local law related to marine and near-shore pollution monitoring and management is completed. Due to the acquired results, the specific prevention measures for maritime activities pollution mitigation are presented. The recommendations based on international practice towards the prevention of marine littering, marine pollution and the introduction of underwater noise energy are provided.

KEY WORDS: marine transport, marine near-shore littering and pollution, underwater noise energy, monitoring system

1. Introduction

The Lithuanian maritime sector has a significant impact on the country’s economy. Besides economic and social realizations, the field of seafaring symbolises the number of environmental issues due to its significant anthropogenic load to nature. Therefore, nautical activities’ strategy should be in accordance with UN Sustainable Development Goals, especially to SDG14 (https://sustainabledevelopment.un.org/sdg14), where conservation and sustainable use of seas and marine resources are the key points of long-term development.

It is obvious, that the maritime industry invests in transportation infrastructure, road and rail connections, and cargo operational facilities. Simultaneously, maritime activities highly depend on a proper environmental management system, that is suitable for paper, plastic, other garbage as well, hazardous waste handling. Therefore, for the marine industry the responsible consumption, production and waste management are the paramount conditions for the successful development of its further activities [18].

A substantial amount of marine waste is generated from shipping activities and shore-based activities at the terminals and their infrastructure. Sea-based sources of marine litter are mostly associated with waste released to the water body by ships, fishing activities, leisure boats, offshore constructions and sea dumping. In the Baltic Sea region, ship board generated waste and abandoned fishing gear is one of the emerging and important issues [11]. In comparison to the OSPAR convention region, about 40% of the marine litter items found on the beaches stem from the sea-based sources, mostly fisheries and shipping [13].

At the same time, the harmful effects of marine debris on the hydrobionts due to their entanglement and ingestion of litter by individuals results in their deaths or serious suffering, as confirmed by the study completed by the European Commission's JRC. Also, risks arise to humans associated with the ship’s propellers fouling and blocked intake pipes, that are regularly reported in European waters. As well, large sized debris may typically affect humans from a molecular (toxicity) to an individual level [26].

Another important issue of the increasing trends in commercial shipping [5] is underwater noise radiated by ships. In 2014 International maritime organization (IMO) Marine Environmental Protection Committee (MEPC) adopted the non-mandatory guidelines with recommendations for commercial ships quietening to mitigate their negative impacts on marine life. These guidelines recommend improving the new ship’s design using quietening developments for ship’s hull, propellers, machinery design and overall design of the vessels. By the date in the Baltic Sea region the recommendations for ships underwater noise reduction is under development (HELCOM, 2016).
A transition period toward a circular economy opens the opportunity for economic sanctions regarding the usage of plastic goods and their production’s limitations. Scientific and technical insights provide the perspectives for innovative suggestions related to sea-based littering sources reduction (reuse, repair, recycling). Educational aspects as well, as societal behaviour can significantly contribute to marine litter prevention [16].

In this article the topics of marine littering and physical pollution are contemplated, which helps to understand the current situation on ship-generated plastics and underwater noise. As well, this article demonstrates the status of the European and worldwide policy addressing mitigation and prevention of pollution reflected in the legal documents and initiatives. Moreover, this paper has the intention to identify the main regulations’ indicators for implementation measures to accelerate the sustainable management of plastics and underwater noise pollution into the marine environment of Lithuania.

2. Methods

The method to estimate potential longshore transport is known as “CERC formula” [8]. The potential longshore transport rate, dependent on an available quantity of littoral material is most commonly correlated with the longshore component of wave energy flux:

\[ Q_l = \frac{K \left( \frac{C_g}{E} \right) \sin \alpha_c \cos \alpha_b}{(q_i - \rho) g (1 - p)} \]  

where \( Q_l \) is the volume transport rate with units’ cubic meters per day; \( \rho_c \) and \( \rho \) respectively are the density of the particles and seawater.

As the density of the microplastic \( \rho \) is (1.05÷1.6) [7] with the density of seawater \( \rho_c = 1003 \text{ kg/m}^3 \) [29]. High-density microplastics are naturally non-buoyant, and usually deposited in sediments from beaches to the deep sea and vice versa due to waves [29]. As the density of the particles is comparable to the sand sand density [7, 29] this approach can be used to predict marine debris transport. The direction of the transported material also is an important factor, as the points of the accumulation can be related to the alongshore transport [23, 24]. The sign of the potential transport rate is usually chosen so that the motion from the left to the right hand of the person looking to the sea is positive. The sign and the value of the integral of the transport rate show the dominant direction and the magnitude of net transport, respectively. \( E \) is the wave energy and \( C_g \) wave group velocity at the breaker line and \( \alpha_b \) is the wave breaker angle relative to the shoreline. \( K \) is the nondimensional coefficient. We employ the following empirical dependence of the coefficient \( K \) on properties of the wave field and sediments [8]. The potential direction of the particle transport mostly depends on the predominant wave direction [21, 25, 30].

The properties of the wave field (significant wave height (m), peak period (s), and propagation direction (deg)) were calculated for each 3-hour time slice at the centroids of the sectors (see Fig. 2), located beyond the surf zone for typical wave conditions for the year 2013, using SWAN wave model [30]. Wind data were taken from the Klaipėda, Palanga and Nida hydrometeorological stations. Given the uncertainty in wind and reverse wave data, a more accurate calculation of debris’ transport is not reasonable.

To evaluate possible marine littering trends from shipping activities an available data of plastic waste delivery to the port reception facilities (PRF) were analyzed from 2010 to 2019 [17]. The correlation coefficients were equated using MATLAB® software, which uses “Pearson’s method”. As well, to evaluate the physical noise pollution from ships at the Lithuanian marine area an available underwater noise pollution data was analyzed, acquired by Bagočius & Narščius [3].

3. Results and Discussion

3.1. Marine Littering from Ships

The analysis of the ship calls to Klaipėda Port data [17] allows us to make an assumption, that ship calls in 2010-2019 have a steady dynamic (Fig. 1) with the slightly decreasing number of international calls (4616 calls per year). In contrast, loaded cargo tonnage increases, where the yearly average of loaded cargoes constitutes 38.36 mil. ton. Delivery of ship-board generated plastics to the port reception facilities increases as well (690 cub.m./year).

The relation between the loaded cargoes and the delivered ship-board generated plastics shows a very strong positive correlation \( r = 0.82 \). This correlation suggests, that in the future with the growing amount of cargoes the amount of ship generated plastics likely will increase. It should be noted, that decreasing number of ship calls versus increasing loaded cargo tonnage \( r = -0.015 \) shows slight increase in ship sizes.

An observation of ship sizes increases is consistent with the ships Energy efficiency design index (EEDI) as well, with the Ship’s energy efficient management planning (SEEMP), the new regulations apply to all ships [15]. According to the study completed by the European Maritime Safety Agency (EMSA) the amounts of solid wastes generated on ships, reaches \( \sim 3 \text{ kg per day / per crew member} \). The generation of plastics varies between 0.001 and 0.008 cubic meters per crew member per day sometimes reaching quantities of 0.025 m³ per crew member / per day (assuming the density of 16 kg/m³) [10]. The ship 2015 AIS data reveals that 70% of the ships calling to Klaipėda Port
are merchant ships, having an average size of the 36540 GT [2]. On the global scale, these ships fall in to the category, having an average crews’ size of 21.8 sailors [27]. These raw estimates let to account for an average amount of plastics generated per day/per vessel at the Lithuanian marine area, which equal the amount of ~0.02 – 0.17 m³ up to 0.55 m³ (~0.35 – 2.8 kg up to 8.8 kg). It is generally expected, that maritime transportation in the EU countries will grow. The contributions from extra and Intra European trades will make a high contribution to maritime transportation. The modal shift of transport from road to the sea is expected to take place in Europe. As well, it’s predicted, that the size of vessels will increase to enable more efficient and cost-saving freight transport in the EU [5]. These estimations and forecasts suggest, that the load of ship-board generated plastics delivered to the PRF will increase in the future.

By the date, scientific findings reveal, that at the EU seas the ingested plastics have been found in the seabirds. Here, 60% of water bird tubenose species were found to be ingesting plastics [26]. Scientific studies completed in the Baltic Sea find plankton and fish with the ingesting plastics. Beer et al. [6] reported the finding of the microplastics of the sizes 0.21 ± 0.15 m³ in plankton samples and the occurrence of microplastics (< 5 mm size) in 20% of the 814 samples of examined Atlantic herring and European sprat in the Baltic Sea during 1987-2015. It's hypothesized that this presence of microplastics in aquatic animals may have a positive correlation with the specific human activities in the Baltic Sea region.

Hence, with the increase in the sizes of ships and loaded cargoes in Klaipeda seaport as well as with the increase of delivery of waste such as plastics to PRF, the amount of marine littering from shipping will inevitably increase, unless appropriate additional measures are considered.

3.2. Transport of Marine Debris

Marine hydrodynamic processes can affect an appearance and distribution of the sea-based pollution at the seashore and transport of the marine debris, which depends on the: (i) amount of the material in the water column; (ii) density of the material; and (iii) hydrometeorological conditions. Historically, the total amount of material moved along the shoreline has been related to the amount of energy available in the waves arriving at the shoreline. Factually, that was applied to the sediment transport, but it also might apply to other similar material, as micro-plastic or even marine litter during the heavy storm conditions [29]. Using CERC method we can find potential debris transport accumulation (Fig. 2).

Such points can be identified between Klaipeda and Šventoji due to the favourable configuration of conditions. On the main part of the Curonian spit coast, the transport rate is small and can be neglected, especially in the part from Juodkrante to Klaipeda. At the same time, points with high anthropogenic pressure such as Klaipeda and Palanga also can get additional pollution to the shore from the sea. The number of sea-based pollution convergence points (Fig. 2) tends a change by a changing of wave climate, especially in the last decade [21].

Although, in the stripe of the coast from Juodkrante to the Klaipeda modelling results shows small debris transport, this part of the Spit is indicated as being under the exposure of marine littering [4]. This exposure to marine littering appears from the considerably high flow of holidaymakers even during cold seasons as this area is in the vicinity of the Port of Klaipeda. While interpreting CERC results and available data it can be assumed that the main pollution source at this stretch of the coast is land-based.

CERC modelling results as well as confirmed by the data found by Balčiūnas [4] indicating the most polluted coastline sectors at Klaipeda and Karklė areas. In this sector modelled results reveals changes of the potential transport direction, which shows favourable conditions for the additional pollution from the sea. Pollution from the sea-based sources more often can be observed on the coast after the heavy storms, when wave driven transport on the coast are predominant [19].
3.3. Underwater Noise Pollution from Ships

Underwater noise is radiated by every passing ship, creating a wide spectrum extending to the frequency band above 10 kHz. The broad peak in the spectrum is produced in the frequency bands within 10 – 1000 Hz [1], produced by machinery noise - radiated through the ship hull, cavitation noise (propeller noise) and hydrodynamic noise [22]). The sound pressure level radiated by ships directly depends on the vessel speed as well, ship size [12]. As noted earlier the trends in increasing shipping sizes are expected within the EU as well, at the Lithuanian ports. However, the Baltic Sea has the limitation of vessel sizes, i.e vessels having the draught above 11 meters, should make special considerations of navigation while entering the Baltic Sea [14]. These limitations let to make an assumption, that increase in vessel sizes in the Baltic Sea has limitations, that will not reduce the number of entering vessels greatly. It’s known that larger vessels tend to generate more noise but their greater carrying capacities off set their higher noise output and vice versa [20].

The acquired underwater noise levels at the Lithuanian Baltic Sea area at two different locations, reveals that areas along the main shipping navigational lanes are considerably affected by radiated ship noise. Fig. 3 shows the spatial distribution of broadband continuous underwater noise, modelled for 2015 January (monthly averages).

The acquired underwater noise levels at two different locations reveal, that the continuous underwater noise levels are greatest at shipping navigational lanes and depend directly on the radiated noise of ships. The median levels at these two locations (black squares in Fig. 3) in July 2015 constituted 95.9 dB at 1st location and 101.5 dB re 1μPa at
Taking into account, the wave climate changes for the last decade, the modelling results based on CERC [19] as well, as the increasing amount of plastic waste from the ships, the threat of the Lithuanian coastal zone pollution is real and needed to be prevented and reduced. Furthermore, the marine environmental situation in the Baltic Sea is complicated by physical pollution, such as underwater noise levels confirmed by existing noise data analysis. Fist, both these negative effects could be managed by legal and organizational solutions. International experience based on MARPOL, HELCOM, OSPAR Conventions as well, as worldwide initiatives Global Partnership on Marine Litter and Regional Seas Conventions and Action Plans application helps to regulate the environmental aspects of waste and especially marine litter, generated by the marine industry in regional and global terms. Second, concerning the ships’ recyling practices maritime companies are seeking compliance with the Hong Kong Convention by using ship-recycling facilities that are ratified by the convention [28]. To obtain noticeable and effective results in the field of prevention and control of pollution of the sea and near shore, one should pay attention to the actions that have already been proposed in European marine practice. These actions are: 1) offering incentives by the state to "whistle-blowers" in ship crews in case of illegal littering; 2) considering voluntary agreements with shipping companies, incorporating effective Measures, i.e. installing cameras at the stern of vessels to monitor discarded garbage and other discharges. Companies agreeing on such measures could be granted certain privileges by the state, as in other Green Certificate systems; 3) improving the monitoring/detection of illegal discharges, i.e. using drones for detection of discharges of garbage [13].

4. Conclusions

The clear tendency of the growing amount of the plastics wastes from the ships as well, as the necessity of the fresh managerial decisions is clarified.

Patches of the marine debris transport from the sea to the land will be the actual question for the next future. To apply full mathematical and physical models of the transport requires more detailed studies on the physical parameters of the different types of litter. This simple approach of the potential particle transport can be involved in the planning of more effective coastal monitoring and beach cleaning purposes.

Anderwater noise pollution is actual in Lithuanian marine waters. Mitigation of noise is feasible through organizational and technical means. However, the most appropriate by the date noise reduction means at Lithuanian marine areas are ship speeds reductions by some degree and the ships rerouting from ecologically important areas, as technical means are difficulty implementable at the national level in present time.

Acknowledgement

The research was supported by RBR (Reviving Baltic Resilience) Interreg-V-A project, grant No. STHB 02.02.00-22-0092/16 of the EU South Baltic Programme 2014-2020.

References

ACOUSTICS, 577-580.
Improving the Dependability Evaluation Technique of a Transport Vehicle

M. Babyak¹, R. Keršys², L. Neduzha³

¹Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St. 2, 49010, Dnipro, Ukraine, E-mail: babjak_tt@ukr.net
²Kaunas University of Technology, Studentu st. 56, 51424, Kaunas, Lithuania, E-mail: robertas.kersys@ktu.lt
³Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St. 2, 49010, Dnipro, Ukraine, E-mail: nlorhen@i.ua

Abstract

The safety of vehicles depends on the dependability of its elements, which should guarantee the trouble-free operation throughout the entire service life. The concepts of "safety" and "dependability" for the vehicle are inseparable. Therefore, all structural components throughout the entire service life before the onset of the limit state must guarantee trouble-free operation of rolling stock with the installed system of maintenance and repair, i.e. be in working condition as long as possible and perform all necessary functions.

Regarding the relevance in predicting the technical condition of a vehicle, authors present improving the dependability evaluation technique of its facility by the value of a safety factor. The impact of actual operating conditions of rolling stock on durability and operability (on the example of a pantograph) is taken into account. The nearest relation between the dependability of a structure and a safety factor and parameters of probability distributions of stresses is determined. Improving the technique can be used to evaluate the dependability of the facility from the viewpoint in the individual prediction of operability and life of the structural elements for the vehicle based on observations over the process of their wear. This will increase the safety and dependability of operation for all complex structures.

KEY WORDS: safety, technique, dependability, vehicle, life, wear, pantograph

1. Introduction

The efficiency of the transport system is characterized by the optimal combination of productivity, cost, and dependability in operation of all units of transport vehicles. It can be evaluated by comparing the necessary and available results of its operation based on the purpose: safe and reliable operation of rolling stock under conditions specified in the technical documentation.

For all modes of transport, "safety" implies the absence of unacceptable risk associated with injury or death, property damage, the environment, etc. Traffic safety is a complex of organizational and technical measures aimed at ensuring trouble-free operation and maintenance of rolling stock, equipment, mechanisms, devices in a constant working condition.

As we know, "reliability" is the facility feature to keep in time, within the established limits, the values of all parameters that characterize its ability to perform the desired functions in the specified modes and conditions of use, maintenance, storage, transportation. Dependability is a complex property that can combine the absence of failures, durability, maintainability, storability, or certain combinations. The definition of these components is based on the "operability" concept. That is a state of an element in which it is able to perform the specified functions with the parameters set by the technical requirements [1, 2].

If we consider any element of rolling stock, the characteristic of its operability is the "service life" – the calendar duration of operation in units of time or kilometrage – that characterizes the operating time. The dependability index of a vehicle has a very specific meaning: it can be accurately calculated, objectively evaluated, measured, and tested.

To increase the dependability of rolling stock, it is necessary to "go through" three stages: structural, technological, and operational, during which the tasks of design, manufacture, operation are solved. The experience of transport companies shows that for safe operation it is necessary to constantly maintain a sufficient level of dependability of structures and their elements. Minimal increase in dependability (even the smallest detail) requires significant research, new technological developments, financial investments, etc [3, 4].

The concepts of "safety" and "reliability" for the vehicle are inseparable. Therefore, all structural components throughout the entire service life before the onset of the limit state must guarantee trouble-free operation of rolling stock with the installed system of maintenance and repair, i.e. be in working condition as long as possible and perform all necessary functions [5].

2. The Relevance of the Research

The undercarriage and electrical equipment of vehicles require such dependability evaluation techniques, the use of which will allow obtaining comprehensive information concerning the conditions and terms of their operation, with


consideration to properties of the structure, functional relation of parts/nodes and many others [6-8].

Carrying out the mathematical simulation, life predicting, diagnostics, application of up-to-date resource-saving production technologies, use of advanced materials, the introduction of "smart systems", etc. allows to expecting an increase of dependability and safety of operation of rolling stock and its elements. This is due to the improvement of structures, which improves not only the dynamic/running qualities, performance figures but also traction and energy characteristics. For example, the introduction of "smart systems" on the current collectors of vehicles to ensure a given voltage level can reduce the level of energy losses in the traction networks of electrified transport to 40 ... 60% [9-12].

Currently, given a number of requirements (including environmental safety), most manufacturers of equipment (as an alternative to internal combustion engines) prefer an electric drive. For example, this applies to the mainline, industrial railway (Fig. 1, a), and public transport (Fig. 1, b). The progressive development of automobiles draws attention not only with hybrid passenger vehicles but also with the creation of powerful trucks with electric traction (Fig. 1, c) [13-16].

![Fig. 1 Interaction with the contact wire of a pantograph on: a – electric locomotive; b – tram; c – car](image)

A common feature of these vehicles is the dependence on the safe and reliable operation of a special element. It is a pantograph.

When designing a pantograph, scientists must take into account the requirements and recommendations that apply to both the design and the permissible operating conditions. For example, in railways, EN 50318:2018 standard is used to evaluate the dynamic interaction between aerial contact wires and the pantograph; to determine the technical criteria for their interaction one used by EN 50367:2012 standard; based on the standard EN 50317: 2012 we determine parameters of simulation; EN 50206-1:2010 standard is used to determine the characteristics and carrying out of tests for pantographs.

Application of dependability analysis methods is regulated by the national standard DSTU 2861-94, it is harmonized with the requirements of the international standard IEC 60300-3-1:2003, which establishes the following approaches to evaluate dependability [16]:

- analysis of the dependability for the facility according to the results of measures and techniques to ensure dependability at the stages of design, production, and operation in order to increase the dependability of the vehicle. It makes it possible to refine its design, manufacturing technology, maintenance and repair systems;
- quantitative methods allow us to predict dependability with regard to the established requirements of maintenance and repair for each element of design of rolling stock and to carry out the comparative analysis of reliability. They also provide the evaluation of operating conditions, causes, and mechanisms of failures, dependability indexes of elements, maintenance strategy, repair, etc.

With relation to the requirements and recommendations of current regulatory documents, the authors propose to improve the dependability evaluation technique on the example of the pantograph.

3. Determining the Safety Factor to Evaluate the Dependability of the Vehicle Element

One of the functionally important structures of modern mainline, municipal, industrial electric transport is a pantograph, which has a rather complex mechanism. It ensures the dependability of the sliding contact with the current-carrying conductor (Fig. 1) and through the contact elements (Fig. 2) transmits electrical energy to the working bodies of the vehicle [10-14].

The pantograph can be studied as an element of a mechanical part that interacts with the rail track or road surface through the vehicle’s undercarriage. Through the contact elements (Figs. 2 and 3) it must withstand all static and dynamic loads from the overhead line (Fig. 1); frequent blows in the places of its joining and fastening; friction with the unevenly worn surface of the contact wire and many others [10, 17-18].

These days, new materials are used for pantographs. Loadbearing structures, which were traditionally made of thick-walled metal, are now being replaced by "lighter" ones made of aluminum alloys. One also tries to make contact elements with as little resistance to electric current as possible, and instead of threaded couplings, conductive adhesives are introduced. With all possible upgrades and design changes, the pantograph must guarantee the safe and reliable
operation of the vehicle. Therefore, there is a need to review studies of structural materials, their interaction, calculations of dependability parameters, and so on [10, 14].

To ensure the operability and failure-free operation of the pantograph, it is necessary to evaluate what affects the durability of its contact elements, which in most cases are made of graphite or copper (Fig. 2). High speeds, adverse weather conditions, etc. cause abrasions, cleavages, cracks, burrs, sawing (Fig. 3). Significant traction current and unreliable contact (Fig. 4) leads, in particular, to the burning and melting of the contact elements (Fig. 5) and the upper part of the pantograph (Figs. 1 and 4). Mechanical failure of one or more contact elements can damage the pantograph as a whole. This confirms the importance of evaluating the dependability of the structure and determining the safety factor [10, 14].

Today, the problem of predicting the technical condition of structural elements (one of the tasks of estimating the dependability of rolling stock) is relevant, takes into account the wear process in order to determine the safety factor [20]. The laws of mechanics and electrical engineering can be applied to almost all elements of vehicles [21]. When studying the processes of wear of contact elements on rolling stock, mathematical models must reflect the nonlinear physical processes occurring in them. They are described using analytical expressions that can be obtained in different ways [8, 16, 21]. In particular:

1) on the basis of the analysis of statistical data on the operating the structural element before a failure in work (life definition);
2) on the basis of the analysis of physical processes of wear for each element (definition of a limit state is a state of a facility according to which its further operation or restoration of its working condition is impossible or inexpedient).

Mostly these laws of stress and strength distribution, which are considered only as an interpretation of the probabilistic nature of the average ratio of strength margin. Evaluating the dependability of the design of the pantograph and its elements, the well-known principles of assessing the dependability of structures are taken as a basis [8, 16, 21]. The group of authors proposes to improve the dependability evaluation technique of the transport vehicle (on an example of the pantograph) by the value of the safety factor, which can take into consideration the impact of real conditions. We propose to analyze new developments and design changes in terms of the safe operation of rolling stock. In particular, by introducing the "safety factor" concept. It is the ratio of the ultimate load to the calculated load. That is, the material and dimensions of all the constituent structural elements must be selected so that under the action of applied forces they are not destroyed [17-19].

The critical range of operation, the nearest relation between the dependability of the structure and the classical safety factor, and the parameters of the probability distributions of stresses in the design of the pantograph are determined for each material of the contact element. We propose due to the probabilistic characteristics of stresses and strengths of each element of the vehicle to combine the definition of their minimum service life with dependability (operability) through the "safety factor" $n$ concept. The main issue (both in theoretical and applied terms) is not the traditional evaluation in the dependability of the general unit/aggregate, but the individual prediction of operability and life of the vehicle design element based on observations of the wear process in operation.

It is known that all contact materials differ in both physical and mechanical properties. It is necessary to evaluate the dependability parameters of the contact element due to its minimum physical strength, which is constantly changing depending on operating conditions – mechanical friction, overheating by high currents, dynamic loads, etc. [22, 23].
Therefore, for each material of the contact element it is necessary to find and minimize the range of work after the last control, in which the minimum strength will be retained. It will provide reliable operation, but there is already a possibility of destruction, which threatens traffic safety (shaded area, Fig. 6) [17]. That is, one needs to determine the limit value of the controlled parameter (it is the minimum height in the contact element of the pantograph), at which the element will still be in an operable state and does not require unreasonable replacement (shaded area Fig. 7).

When studying the kinematics and dynamics of pantographs, the main task is to choose the appropriate value of the safety factor $n$, which corresponds to a certain level of structural dependability $R$. This choice is based on the analysis of the failure parameters of the various components in the pantograph, on which random variables of the tensile strength $S$ with probability density $f_1(S)$ (Fig. 6) and stresses $s$ with probability density $f_2(s)$, determining the conditions of non-destruction. Since values $S$ and $s$ are random, than the value of safety factor $n$ also will be random with probability density $f_3(n)$. Probability densities $f_1(S)$, $f_2(s)$ and $f_3(n)$ have average values $\bar{S}$, $\bar{s}$, $\bar{n}$ and the coefficients of variation of the tensile strength $V_s$, stress $Vs$ and safety factor $V_n$.

Defining safety factor $n$ is probabilistic and requires that in a reliable design, its value would be more than one. If we accept $n = \frac{S}{s}$, and the distribution of the strength limit $S$ with probability density and stress $s$ are described by normal laws (Fig. 6), then probability of the condition of non-destruction of the element determines its dependability $R = P(n > 1)$. The shaded area (Fig. 7) demonstrates the value of the structural dependability $R$, which depends on the extent to which $f_1(S)$ and $f_2(s)$ "overlap" (Fig. 7) and it is defined as:

$$R = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f_1(S) dS f_2(s) ds .$$  

(1)

To calculate value $R$ we apply a graphical method (Fig. 7). It is determined by the area under curve of ordinate $f_3(n)$ in the interval from $n = 1$ to $n = \infty$ provided that value $f_3(n)$ is set by the density of functions $f_1(S)$ and $f_2(s)$. Values $\langle a \rangle$ and $\langle \varepsilon \rangle$ (Fig. 7) are arbitrary positive amounts taken by a random value of the safety factor $n$. If $n$ is within the range $|n-a| \leq \varepsilon$, we get the inequality:

$$P(|n-a| \leq \varepsilon) \geq 1 - \frac{E \left( (n-a)^2 \right)}{\varepsilon^2} .$$  

(2)

Accepting that $a = k \cdot \bar{n}$ and $(a-\varepsilon)=1$, inequality (2) for all cases (when an arbitrary constant value $k > 1$) it can be represented as:

$$R \geq 1 - \frac{1}{n^2} \left[ \frac{V_n^2 + (1-k)^2}{(k \cdot \bar{n} - 1)^2} .$$  

(3)

The sign of inequality (3) indicates the lower limit of possible values of reliability. Assuming that the arbitrary constant value is $k = 1$, its critical value is $k^* > 1$, the sign corresponds to a larger value of the lower limit of reliability. Therefore, having performed calculations, we rewrite (3) as follows:
\[
\overline{n} \geq \frac{1}{1 - V_{s} \sqrt{\frac{R}{1 - R}}} \quad (4)
\]

The obtained expression allows evaluating the smallest value of the average safety factor, which provides no less (then \( R \)) probability of finding a value \( n \) in range \( 1 < n < \left(2k^* \cdot \overline{n} - 1\right) \), and its lower limit is determined by the equal sign.

Fig. 8 presents graphs of the relationships between values \( \overline{n} \) and \( V_{s} \), corresponding to different levels of dependability in the pantograph \( R \). Dependencies determined according to inequality (4) are shown with solid lines, and dependencies obtained according to well-known calculations of dependability indexes are dashed lines.

Fig. 8 Dependencies of the safety factor on the reliability

Statistical characteristics of distributions \( f_{1}(S) \) and \( f_{2}(s) \) are determined on the basis of a sufficiently large number of observations through average value \( \overline{n} \). To establish more stringent boundaries, taking into account the operating conditions, we propose to perform the evaluation for dependability of elements in the pantograph through the “central” safety factor \( n_{c} \). Neglecting members of higher orders (greater than two) values \( V_{s}^2 \) and \( V_{s}^2 \) we write down an expression to determine the smallest value \( n_{c} \), at which the probability of setting the value of the safety factor within range \( 1 < n < \left[2k^* \cdot n_{c} \left(1 + V_{s}^2\right) - 1\right] \) will be not less than value \( R \):

\[
n_{c} \geq \frac{1}{1 - \sqrt{\frac{V_{s}^2 + V_{s}^2}{1 - R} - V_{s}^2}} \quad (5)
\]

Using expressions (4) and (5), it is possible to construct calculated nomograms to evaluate the dependability and study its dependence on the safety factor, given the design features of vehicle elements both at the design stage and during their operation.

4 Conclusions

Due to the relevance in predicting the technical condition of structural elements, authors carried out improving the dependability evaluation technique of the vehicle facility (on the example of the pantograph) by the value of the safety factor. This will take into account the impact of real operating conditions of the rolling stock element on its durability and operability.

In real conditions, improving the technique gives an individual prediction of operability and life based on observations over the process of vehicle elements wear. This can be one of the options for calculating the need for withdrawing from the service of extremely worn parts. It is advisable to replace them not completely for all elements during scheduled repairs, but after the control period, depending on the calculated safety factor. In practice, the improvement of the technique will also allow us to refine the calculations by other techniques, evaluating the safety factor for the components. This will increase the safety and operational dependability of the transport vehicle.
References


Heat Resistance of Ti-Al-Si-Cr-N Coatings with Different Structure for Titan Alloy-based Parts of a Gas Turbine Engines

K. Savkovs¹, M. Urbaha²

¹Department of Transport systems and Logistics, Institute of Aeronautics, Riga Technical University, Kalku str.1, LV-1658, Riga, Latvia. E-mail: sakon@inbox.lv
²Department of Transport systems and Logistics, Institute of Aeronautics, Riga Technical University, Kalku str.1, LV-1658, Riga, Latvia. E-mail: Margarita.Urbaha@rtu.lv

Abstract

Perspective titanium alloys are successfully used in modern aviation gas turbine engines (GTE). However, their use is limited by low heat resistance at temperatures higher than 700°C. The paper deals with the results of research of Ti-Al-Si-Cr based thin (up to 10 microns) heat resistant ion-plasma coatings for titan alloy-based parts of a gas turbine engine (GTE). To carry out the research, three Ti-Al-Si-Cr based alloys with different microstructure were taken: intermetallic, conglomerate, and nitride. The analysis of surface oxidation process in the range of 700°–850°C with the use of scanning electron microscopy was performed and the key features of the coatings destruction process under high-temperature oxidation conditions were identified.

KEY WORDS: gas turbine engines, heat resistance, ion-plasma deposition, intermetallic, conglomerate, nitride

1. Introduction

Ion-plasma coatings are widely used in industry to improve the operational properties of various parts of machines and mechanisms.

The use of these coatings in aviation is especially actively developing, where they are used mainly for various parts of aircraft gas turbine engines (GTE).

Coatings can have different purposes: wear-resistant [2], heat-resistant and corrosion-resistant, conductive and electrical insulating and others with specific functions (shielding, selective, etc.). Often coatings simultaneously perform several tasks, for example, increase wear resistance and at the same time are corrosion resistant, etc.

One of the important directions in the development of coatings is to increase the heat resistance of the parts of the hot path of gas turbine engines (GTE) - blades of the turbine [10], nozzles, and parts of the combustion chamber. Recently, the blades of a high-pressure compressor, the last stages, have been added to these parts that are standard for a hot path. This is due to the current trend in the design of engines to increase the compression ratio of the high pressure compressor (PC) and the engine as a whole, which leads to an increase in air temperature in the last stages of the compressor. In promising engines, the PC can reach (32 ...,) [1]. Such an increase in the compression ratio of the compressor and an increase in the flight speeds of the aircraft leads to an increase in air temperature in the last stages of the compressor (650–700°C).

Promising titanium alloys including intermetallic Ti-Al alloys, which are often used for compressor stator vanes and, recently, for turbine vanes having a set of unique properties, at temperatures of 700–850°C show a significant drop in heat resistance while maintaining high strength. This is due to the formation on the surface of scale based on TiO2, a needle-like type, prone to rapid growth with subsequent detachment.

Exfoliation leads to a violation of the aerodynamic and weight characteristics of the blades up to the destruction of the output edge. This significantly limits the temperature range of application of these alloys or significantly reduces the operational durability of parts made of titanium alloys, which leads to their frequent replacement during repair and, accordingly, increased costs for engine repair and a decrease in the overhaul life.

To solve this problem, coatings [1-5] are being developed and used on the basis of various materials often used to increase the heat resistance (Al, Si, Cr, Zr, B) and much rarer and more expensive ones as Pt [9]. Coatings are applied in various ways — diffusion saturation, plasma, detonation, electron beam [10] and vacuum deposition, and usually have a thickness of tens of microns [6-8]. Each of these methods has its advantages and disadvantages.

2. The Purpose of the Work

This work describes the study of the oxidation of titanium alloys with thin vacuum ion-plasma coatings based on (Al-Ti-Cr-Si) + N obtained at various nitrogen partial pressures in the deposition chamber. A feature of these coatings is that they were specially created for the blades of the last stages of the GTE compressor, in which the thickness in the maximum section does not exceed 1.5 mm. With such thicknesses, the use of coatings over 10 μm can already change the aerodynamic profile of the blades and, therefore, the flow regime, which can affect the operation of the compressor and the engine as a whole. For turbine blades made of titanium alloys, this does not matter because of their significantly
greater thickness (3 mm or more)

3. The Methodology of the Experiment

For the experiment, samples were selected from the VT-1 titanium alloy with the lowest degree of alloying. This was done to toughen the testing of coatings containing (Al-Ti-Cr-Si) + N, since the coating resorption effect will be most intense on these alloys (one of the main reasons affecting the durability of coatings) due to a higher gradient in the concentration of alloying elements between the coating and the base.

Three types of coatings of similar composition were selected for testing, but differing in microstructure — intermetallic sample 148, conglomerate sample 151 and nitride sample 154, and a sample without coating — WO.

All three coatings were applied to equipment HHB-6,6-11, under the identical deposition scheme (Fig. 2). Only the partial pressure of nitrogen in the deposition chamber changed. For the intermetallic structure, the partial pressure was -0 mm. Hg, conglomerate 0.2-0.4 x 10^{-3}, and nitride 1.5-1.6 x 10^{-3} mm. Hg.

The study of heat resistance was carried out in an electro furnace atmosphere using the following regime: heating the furnace to the desired test temperature, loading the samples into the furnace, 2-hour exposure, unloading and cooling in the air. The tests were carried out at the furnace temperatures of 700°, 750°, 800°, 850°C. Heat resistance was assessed on the basis of samples weight change after each test cycle (Fig. 3). The protective properties were evaluated by the efficiency coefficient — the relation of reference sample mass gain to the tested sample mass gain at all testing temperatures (Fig. 4). As a result of the tests, the following features were revealed (Figs. 2-7).

Fig. 1 Schematic diagram of obtaining a conglomerate coating

Fig. 2 The appearance of samples with coatings 148,151,154 and a sample without coating (from left to right) after testing

Fig. 3 Change of sample mass during the oxidation test
During the tests, the microstructure of the coatings is gradually changing due to oxidation and diffusion processes. There are no considerable changes in the coating microstructure up to a temperature of 750°C, except for the colour of the coatings which changes due to the formation of a thin oxide layer on the surface without any substantial changes to the gloss. At temperatures above 800°C, a needle structure typical of titanium oxide begins to form mostly
on samples 148 (Fig. 5) and partly on 151 (Fig. 6); and increases at 850°C. As a result, the surface loses some of its gloss and becomes more matte. The surface of the uncoated sample is matte in the whole temperature range, and as the temperature increases, the colour of the coating gets more yellow. At a temperature of 850°C, the delamination of oxide begins.

The resistance of coated samples and kinetics of oxidation was evaluated by the change of their mass during the tests. (Fig. 3). The efficiency of coatings was evaluated by the ratio of the coated sample mass gain to the uncoated control sample mass gain (Fig. 4).

All the above specified coatings showed high resistance during the tests below 750°C with a maximum efficiency of 150 (conglomerate coating) – 50. At a temperature of 800°C, the effectiveness of coatings decreases slightly, but remains at a very high level - 38 for intermetallic and 28.5 for the conglomerate. The efficiency of the nitride coating remains average over the entire temperature range, but reaches a maximum of 10 at a temperature of 800°C. But at the same time, the nitride coating has a smaller area of the needle oxide zone. At a temperature of 850°C, the measured efficiency of all coatings decreases - (the maximum efficiency remains with the conglomerate coating - 2.85). Such a significant decrease in the measured efficiency is due to a significant detachment of the scale from the sample without coating. As a result, the weight gain is reduced and the actual effectiveness of the coatings is underestimated.

4. Conclusions

1. Ti-Al-Cr-Si-N thin coatings with different structures – possess rather high short-term oxidation resistance within the range of 750–800°C with maximum efficiency 50.
2. The resistance of a coating is determined by the intensity of needle structure formation based on titanium oxide. The needle structure spreads from certain centres of a coating that probably have some local faults and lower protection from penetration of basic titanium alloy oxygen.
3. The conglomerate coating is most efficient up to a temperature of 750°C and at 850°C. Intermetallic coating more resistant at 800°C.
4. The nitride coating has less effectivity in the full range of temperature, with the maximum effectivities at 800°C -11,4 But at the same time, the nitride coating has a smaller area of the needle oxide zone in comparison with other coatings.
5. All types of Ti-Al-Cr-Si-N coatings can be used both as single-layer coatings and as a part of multilayer coatings intended for the protection of titanium alloys from high-temperature oxidation.

Acknowledgements

This work has been supported by the European Regional Development Fund within the Activity 1.1.1.2 “Post-doctoral Research Aid” of the Specific Aid Objective 1.1.1 “To increase the research and innovative capacity of scientific institutions of Latvia and the ability to attract external financing, investing in human resources and infrastructure” of the Operational Programme “Growth and Employment” (No. 1.1.1.2/VIAA/1/16/126 “Development of innovative metal-ceramic nanostructured coatings (McBLADE)”).

References

Assessment Requirements TSI CCS for the Trackside Subsystem in the Field of GSM-R Coverage

M. Sumila¹, K. Tchórzewski², M. Sawicka³

¹Railway Research Institute, Chłopickiego 50, 04275, Warsaw, Poland, E-mail: msumila@ikolej.pl
²Railway Research Institute, Chłopickiego 50, 04275, Warsaw, Poland, E-mail: ktchorzewski@ikolej.pl
³Railway Research Institute, Chłopickiego 50, 04275, Warsaw, Poland, E-mail: msawicka@ikolej.pl

Abstract

The article presents issues related to the problem of verification of the requirements of the TSI CCS [3, 5] imposed on a Notified Body in the assessment of basic parameter 4.2.4, i.e. measuring GSM-R signal coverage. Notified Body carries out tests in the aspect of the integration of Control-Command and Signaling Trackside Subsystem (CCT) with rolling stock as a Control-Command and Signaling Onboard Subsystems (CCO) described in TSI CCS, Table 6.3 [4]. The article discusses the requirements of CCS TSI described in EIRENE documents [7, 8], then discusses the research methods used during radio tests. The final part presents the results of an exemplary GSM-R radio measurement and analysis of radio test results.

KEY WORDS: GSM-R, TSI CCS, radio signal measurement

1. Introduction

The railway interoperability Directive 2008/57/EC of 17 June 2008 [6] sets out conditions for achieving railway interoperability within the European Union. These conditions concern many different aspects of the railway system connected with its operation and maintenance. The GSM-R (Global System for Mobile Communications – Railways) system is set as a railway radio communication European standard. The railway interoperability radio standard forced the introduction of common technical standards specified in EN 301 515 [9] and TS 102 281 [10] but the main requirements for GSM-R are set out in EIRENE SRS [8] and EIRENE FRS [7].

In the Directive 2008/57/EC [6], GSM-R is the key element of the concept of rail system interoperability in Europe. The essential requirements in this respect are set out in the Technical Specification for Interoperability (TSI) relating to the “Control-Command and Signalling subsystems” (CCS) [2]. Radio communication functions are described in the point 4.2.4 as “Basic parameters” and are implemented in the CCO and CCT subsystems by:

- Basic communication function (parameter 4.2.4.1);
- Voice and operational communication applications (parameter 4.2.4.2);
- Data communication applications for ETCS (parameter 4.2.4.3).

The institutions responsible for assessing the above parameters within the scope of Directive 2008/57/EC [6] on the interoperability of the rail system in the EU are Notified Bodies (NoBo). A NoBo is designated to evaluate and verify the above mentioned rules in an objective, impartial and independent manner in relation to the entity of the product it assesses. It fulfills the function of a third party in the process of conformity assessment and verification constituents or subsystems to achieve the certificate of interoperability. The list of Notified Bodies is available in the Nando database [11].

Assessment and verification processes of constituents or subsystems are carried out within the scope of a chosen module described in Decision 2010/713 [3]. In the case of assessing a GSM-R network NoBo has to verify Control-Command and Signalling Trackside Subsystem and the basic parameters pointed in table 4.1 TSI CCS [4]. With regard to the GSM-R network, NoBo is obligated to assess Integration with Control-Command and Signalling Onboard Subsystems with rolling stock in the scope of the basic parameter i.e. GSM-R signal coverage written in table 6.3. The proof of assessment is “On site measurements”. For these reasons, during the verification process, NoBo is required to conduct field tests of the GSM-R network and confirm the minimum level of radio coverage. A closer analysis of the issue imposes on NoBo the necessity of applying the criteria indicated in TSI CCS and also of choosing the proper method to perform the radio measurement.

The following part of the article presents the requirements indicated in EIRENE [7, 8] requirements for radio coverage for the GSM-R network and the consequences of these requirements. Next, two measurement methods will be described and compared, taking into account their popularity and usefulness. Finally, an example of NoBo measurements will be presented and discussed.

2. Requirements of GSM-R Radio Coverage and Assessment

The coverage level is defined in EIRENE SRS [8] as the field strength at the height of the antenna mounted on the roof of a train. It is assumed that nominally the height of the antenna is 4 m above the track. The coverage level is
defined for an isotropic antenna with a gain equal 0 dBi. To correct the gain of a real antenna it is necessary to apply appropriate corrections to achieve proper results of the measurement. The coverage criterion will be met with a certain probability in the coverage area. Based on the knowledge of those conditions of the radio signal propagation, the coverage power level depends on the statistical fluctuations caused by the slow and fast fading [16]. The problem will be discussed in more detail in point 3. EIRENE SRS [8] define a mandatory minimum level for radio coverage for an interoperable GSM-R network:

- 38.5 dBµV/m (-98 dBm) and coverage probability of 95% for voice and non-safety critical data;
- 41.5 dBµV/m (-95 dBm) and coverage probability of 95% on lines with ETCS (European Train Control System) levels 2/3 for speeds lower than or equal to 220 km/h;
- 44.5 dBµV/m (-92 dBm) and coverage probability of 95% on lines with ETCS levels 2/3 for speeds above 280 km/h;
- and between 41.5 dBµV/m and 44.5 dBµV/m (-95 dBm and -92 dBm) and coverage probability of 95% on lines with ETCS levels 2/3 for speeds above 220 km/h and lower than or equal to 280 km/h.

In addition to this, the EIRENE FRS, point 3.2.2 [7] indicates that the probability of the coverage level of radio signal should be at least 95% of the time over 95% of the designated coverage area for the GSM-R Cab radio installed in a vehicle with an external antenna. The interpretation of the indicated requirements is that the coverage hole greater than a total of 5 m in every 100 m of a railroad track cannot be accepted by NoBo [19]. The results are calculated on all the samples collected on the BCCH (Broadcast Control Channel). An example of such an assessment is shown in Fig. 1.

![Fig. 1 Example of radio signal measurement and classification of test results](image)

The example in Fig. 1 presents generic results of GSM-R coverage testing for part of a railway line. The assessment of radio coverage is fulfilled for the first 100 m tested section and is not for the next 100 m section of the railway track. Such verification may lead to an erroneous assessment if the sum of the holes in the radio coverage lies between evaluated sections. In order to exclude such situations where a hole between two adjacent 100 m sections is not acceptable, the method of a sliding window can be used. The method is presented UIC book [17]. The rule of the 1 m increment step of measurement is presented in Fig. 2.

![Fig. 2 The idea of a sliding window and the detection of holes in radio coverage](image)

As can be seen in Fig. 2, the use of the sliding window mechanism in subsequent measuring steps allows a correct verification of a qualified tested railway line in terms of the EIRENE criterion. Fig. 2 shows the example of the following test results for a line equipped with ETCS Level 2 where the criterion is -95 dBm. In this example, sections from 1 to 100 m and from 101 to 200 m should be qualified as meeting the requirements of EIRENE SRS [8] because each of these sections, holes in the coverage of radio signal along a railroad track does not exceed the statutory requirement of 5%. The use of the sliding window method shows that from the third step to the 198 steps the radio signal does not meet the criterion and arises up to 8 m.
3. Measurement Method

3.1. Fading’s Problem

There are many methods for measuring radio coverage [1, 2, 12-14]. Depending on the method, the measurement can be triggered by the distance traveled or by time. Some of them have been documented and published by CEPT or ITU-R. Some of them take into account various environmental factors (i.e. type of terrain, speed of mobile station) and scenarios for using a mobile phone. They can also take into account: multipath propagation, weather condition (particularly rain), shadowing from obstacles affecting wave propagation. Apart from the signal strength at a particular point on the network will vary in a function of time. In wireless communications such fluctuation is known as fading [16, 18]. Fading is often modeled as a random process and described by one of the models e.g.: Nakagami fading model, Log-normal shadow fading model, Rayleigh fading model, Rician fading model, Weibull fading, etc. In general, two types of fading are considered: slow fading and fast fading [16].

Slow fading arises when the coherence time of the channel is large compared with the delay requirement of the application. In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. The received power change caused by shadowing is often modeled using a log-normal distribution with a standard deviation according to the log-distance path loss model.

Fast fading occurs when the coherence time of the channel is small compared with the delay requirement of the application. In this case, the amplitude and phase change imposed by the channel varies considerably over the period of use. This type of interference has an impact on the final radio measurement result and cannot be directly used to assess the radio coverage. For these reasons, different methods are used to average the measurement results. A result of averaging, fast fading should be smoothed without significantly affecting existing slow fading.

Figure 3 presents a graph illustrating of the impact of the averaging process on test results. The light gray line shows too much blur during the averaging process. This leads to the alleviation of slow fading which happens during a long period of time. Incorrect averaging parameters can also lead to the situations presented in Figure 3 as dots. The fast fading effect is still visible on the charts after averaging. Other variables in the figure are not applied in this article and will not be explained further.

![Fig. 3 Calculation of the radio signal strength using different values of averaging [20]](image)

3.2. Method of Averaging

The radio coverage measurement must take into account the indicated EIRENE requirements and as it was written before, it cannot be directly taken from raw measured samples but has to be averaged in the postprocessing calculation to estimating mean values in a given place. The choice of the method is not pointed by GSM-R specifications but a chosen method must allow ensuring indicated parameters.

One of the most popular and used methods is the Lee method [15]. The method was developed in the eighties of the last century and it is widely applied for the needs of public cellular networks. Lee used appropriate mathematical transformations for describing observed physical phenomena. It allows him to obtain the proper values of the necessary parameters to achieve the local mean values: the minimum number of samples, a necessary distance for uncorrelated samples within an averaging window length to properly average the samples.

The values for those parameters were obtained by Lee for a Rayleigh distribution in the UHF band, and have been accepted and widely promoted by ITU-R [12] and CEPT [1] but the use of the method by NoBo raises reservations. The main reason is the assumption within the Lee method that it allows determining an average value of the signal for a distance corresponding to the length of 40 $\lambda$ [15] or 50 $\lambda$ [12] with the probability of 0.9 while ERIENE SRS [8] requires probability at the level 0.95. For this reasons Lee method does not allow verification of the EIRENE criterion.
The authors of the article propose another method of estimating mean signal strength. The method has been proposed by Parsons [16]. He developed a similar study as Lee, however, he distinguish samples taken from a receiver with a linear or a logarithmic characteristic. The analysis was based on the model of the Rayleigh channel, too. The obtained results were \(2L = 22\lambda, N = 57\) for a linear receiver, and \(2L = 33\lambda, N = 85\) for a logarithmic receiver were different for \(\pm 1\) dB and for 90% confidence. Parsons also considered the necessary distance between uncorrelated samples. The minimum distance was calculated and is equal to 0.38\(\lambda\) for the 900 MHz band. Moreover, the author of the method found adequate parameters for expected by NoBo 95% level of confidence for the estimation of mean signal strength in dB. Moreover, he found the proof that the confidence interval decreases very slowly for a large number of \(N\) but the smaller confidence interval necessitates a much larger number of samples \(N\) and correspondingly larger measurement distance. Table presents the results which obtained a 95% confidence level.

A comparison of the aforementioned methods shows differences in the field of the length of the averaging interval and the necessary number of samples. In addition to this, Parsons shows that the acceptable maximum distance used for averaging should not exceed 20 – 25 m to prevent apparent slow fading. For the above calculations (wavelength 900 MHz, length of averaging 48\(\lambda\)) the distance is about 16 m. the comparison of described methods presents Table.

### Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>(f)</td>
<td>923 MHz</td>
</tr>
<tr>
<td>Median field strength probability</td>
<td>(</td>
<td>\bar{z}</td>
</tr>
<tr>
<td>Confidence interval</td>
<td>(P(z \leq Z))</td>
<td>90%</td>
</tr>
<tr>
<td>Accuracy interval</td>
<td>(\pm 1) dB</td>
<td>95%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>(\sigma) (dB)</td>
<td>3.65</td>
</tr>
<tr>
<td>Length of the averaging interval</td>
<td>(2L)</td>
<td>40(\lambda) (13m)</td>
</tr>
<tr>
<td>Number of samples</td>
<td>(N)</td>
<td>36</td>
</tr>
<tr>
<td>Distance between uncorrelated samples</td>
<td>(d)</td>
<td>0.5(\lambda) (in theory)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8(\lambda) (from the measurement)</td>
</tr>
</tbody>
</table>

#### 3.3. Method of Sampling

Another important issue in the process of verifying GSM-R radio signal coverage is choosing a method of triggering measurement pulses. Methods of averaging the strength of the measured signal presented above determine the number of samples as a function of the road. The accuracy and regularity of the measurement samples obtained as a function of road translate into the credibility of the average measurement. Recommendation ITU-R SM.1708-1 [13] indicates that the signal generated by the sensor installed on one of the non-drive running wheels of the measuring vehicle is intended to trigger measurement pulses with appropriate resolution. The indicated solution allows us to taking measurements in tunnels, under flyovers or during adverse weather conditions. All these factors would have a negative impact on the continuity of measurement where a GPS-based signal triggering system is used. In such a case, the number of samples can vary on the same distance because of the variation of measurement vehicle speed and as a consequence determining of the required 100-meter measuring sections.

Authors of the article, in their GSM-R measuring practice tested mechanical odometers as a triggering method. Using the running wheel with knowing parameters such as the scanner's operating frequency, measuring vehicle speed and vehicle wheel diameter allows us to determine the precise measurement resolution as a function of speed.

#### 3.4. Results

An example of the results of testing GSM-R radio coverage in the measurement campaign performed by a Polish NoBo presents Fig. 4.

The graph presents in different colours four from nineteen radio channels in the UIC band (GSM-R spectrum) and shows real raw samples, which were taken from a railway line in Poland. High precision of the samples taken gives the possibility of using any method of averaging. Also, the use of a mechanical odometer ensures a high presence in the location of holes in the radio coverage and a constant interval between subsequent samples. The dispersion of adjacent samples illustrates the uncertainty of subsequent measurements and signal variation due to fast fading. It is presented in the form of individual measurement samples that are situated far from the main trend line (see Fig. 5). Slow fading can be determined by setting a trend line on a large number of samples.

In many cases, fast and slow fading can cause mendacity of the real level of the measured radio signal. As a result of the described situation, it can provide an assessment problem for NoBo in case of a low signal level close to the level of acceptance. For this reason, it is particularly important to use the correct method of averaging the collected measurement samples to obtain a reliable result with the desired confidence level.
4. Conclusions

Over the years, it has been confirmed that radio communication systems are a useful tool for the railway. The introduction of the idea of interoperability of the railway system in the EU [5, 6] has forced GSM-R as a common radio system for these reasons. Among many quality parameters describing real GSM-R radio network [9, 10], the TSI CCS specifications [2] indicate the scope of tests and assessment performed by independent notified bodies in processes of certification. Among them, the confirmation of the radio coverage parameter plays a significant role in the railway area. The quality of radio coverage is tested and assessed by a NoBo. The assessment criteria are indicated in EIRENE [7, 8] and should be tested by using appropriate methods averaging the random fluctuations of the radio signal. Two of them are indicated in the article. The Lee method [15], despite being very popular among public network developers, does not meet the requirements of EIRENE. The method proposed by Parsons [16] does not have these limitations, but requires a larger number of samples to average. Also, the article proposes a method to verify the requirement of 95% radio coverage through better verification using the sliding window mechanism.

Reliable application the one from two presented methods of measurement is based on the accuracy of collecting measurement samples. Measurement experiments show that the most advantageous is the use of mechanical odometers, which are much more accurate for uniformly collecting samples of radio signal strength as a function of the path. The railway environment allows the use of radio and laser odometers for radio coverage measurements, but as a rule, such measurements are subject to a greater error than in the case of mechanical odometers. The worst case is the use of GPS solutions because it prevents the collection of samples in a function of the road as well as in case of a weak GPS signal reception.

The article highlights the issues related to the assessment of the reliability of GSM-R radio signal measurement by NoBo. Unfortunately, EU legislation does not indicate precisely which measurement method should be used unconditionally. In borderline situations, when the radio signal reaches the minimum value in a given section of the railway line, the adoption of one of the described methods of statistical treatment may decide about the formal but not necessarily real success of the project. It is natural that companies building the GSM-R system in difficult and debatable cases, often being under pressure the deadline of the project, face the temptation to adopt a more favorable statistical method to achieve the goal of confirming the requirements. The indicated potential practice obviously translates into any NoBo, which in this case will find itself in a difficult position. The lack of precisely indicated measurement methods and the method of statistical processing the measured samples in the appropriate technical specifications or standards significantly hampers the right decision on the acceptance of the measurement results achieved for the GSM-R network system. It is a problem that, despite the imminent completion of the GSM-R system project in Europe, is still valid and worth solving.
References

2. CEPT, ERC/REC/(00)08. 2003. Field Strength measurements along a route with geographical coordinate registrations.
10. ETSI TS 102 281. 2016-02. Railways Telecommunications (RT); Global System for Mobile communications (GSM); Detailed requirements for GSM operation on Railways. Version 3.0.0.
The Effectiveness of Ship's Position Using the Laws of Distribution of Errors in Navigation Measurements

D. Astaykin¹, A. Golikov², A. Bondarenko³, O. Bulgakov⁴

¹National University “Odessa Maritime Academy”, Didrikhson 8, 65029, Odessa, Ukraine, E-mail: astaykindv@gmail.com
²National University “Odessa Maritime Academy”, Didrikhson 8, 65029, Odessa, Ukraine, E-mail: agolikoff@gmail.com
³National University “Odessa Maritime Academy”, Didrikhson 8, 65029, Odessa, Ukraine, E-mail: bondandrey@ukr.net
⁴National University “Odessa Maritime Academy”, Didrikhson 8, 65029, Odessa, Ukraine, E-mail: aleksandrbul2008@mail.ru

Abstract

This article highlights the assessment of the effectiveness of the coordinates of the vessel, calculated by the least square’s method in the case of mixed distribution of errors in navigation measurements of the sample for three possible sequence options. The results of the researches can be applied in the navigation for the accurate fixed position.

KEY WORDS: the safety of navigation; error of the navigational measurement; laws of distribution

1. Introduction

In a number of cases the statistical treatment of data of the error of the navigational measurement, which was obtained by means of in situ observations, has shown that their histograms are not described satisfactory by means of normal law of distribution. In papers [1, 5] it is shown as well that errors of the navigational measurements do not follow normal law. The models of mixed distribution of different types are considered in papers [1, 3, 4, 6]. Mixed distribution laws, density of which is expressed in an explicit form have been obtained in paper [7], however, the situation in which an original sample contains normally distributed errors of navigational measurements with various variances has not been taken into account, determines the subject area of the present paper.

The purpose of the article is efficiency evaluation of ship’s coordinates calculated by means of least-square method in case of the mixed distribution of navigational errors measurement sample.

2. Presentation of Main Material

Let us assume that errors of the total sample are normally distributed random variables that belong to various particular samples with a defined value of variance \( \sigma_i^2 \). In other words, the total sample is a mixture of particular samples of normally distributed errors with various variances, the wherein the standard deviation of samples \( \sigma \) is discontinuous distribution with values \( \sigma_1, \sigma_2, ..., \sigma_n \) with probabilities \( p_1, p_2, ..., p_n \). In this case density of distribution of the total sample appears as follows \( f_s(\xi) \):

\[
f_s(\xi) = \sum_{i=1}^{n} f_i \left( (\xi, \sigma_i) \right) p_i.
\]

Taking into consideration the expression for normal density \( f_i(\xi, \sigma_i) \), we will obtain:

\[
f_i(\xi) = \sum_{j=1}^{n} p_j \frac{1}{\sqrt{2\pi\sigma_j}} \exp \left( -\frac{\xi^2}{2\sigma_j^2} \right).
\]

The density of distribution \( f_s(\xi) \) depends on values \( n, p_i \) and \( \sigma_i \) wherein the following formulas must be kept:

\[
\sum_{i=1}^{n} p_i = 1,
\]

\[
\sigma_n^2 = \sum_{i=1}^{n} p_i \sigma_i^2.
\]
The set of probabilities \( \{ p_i \} \) is defined by Eq. (3). Let us consider the sets each term of which varies proportionally relating to the minimum value, i.e. one has a formula:

\[
p_i = p_{\text{min}} + i \Delta p.
\]

Value \( \Delta \) is found from the equation:

\[
\sum_{i=1}^{n} (p_{\text{min}} + i \Delta p) = 1,
\]

whence

\[
\Delta p = \frac{1 - np_{\text{min}}}{\sum_{i=1}^{n} i}.
\]  \hspace{1cm} (5)

The analysis of expression (5) shows that value \( \Delta p \) depends on parameter value \( p_{\text{min}} \), wherein with value \( p_{\text{min}} = 0 \) value \( \Delta p > 0 \) takes the largest value \( \Delta p = np_{\text{min}} / \sum_{i=1}^{n} i \), in case of increasing \( p_{\text{min}} \) up to value \( p_{\text{min}} = 1/n \) value \( \Delta p \) becomes zero and the sequence \( \{ p_i \} \) contains equal values \( p_i = p_{\text{min}} \). With further increasing \( p_{\text{min}} > 1/n \) value \( \Delta p \) becomes negative and the set of probabilities \( \{ p_i \} \) becomes decreasing, in this case, some not large value exists:

\[
p_{\text{min}}^{\text{w}} < \frac{n}{n^2 - \sum_{i=1}^{n} i}.
\]

Wherein the last term \( p_{\text{w}} \) of decreasing set \( \{ p_i \} \) is positive.

The set of standard deviations \( \{ \sigma_i \} \) is defined by selected set \( \{ p_i \} \) taking into account the condition (4), wherein set \( \{ \sigma_i \} \) contains proportionally variable terms \( \sigma_i \) in accordance with dependence:

\[
\sigma_i^2 = \sigma_{\text{min}}^2 + i \Delta \sigma_i^2.
\]

Value

\[
\sigma_m^2 = \sum_{i=1}^{n} p_i \left( \sigma_{\text{min}}^2 + i \Delta \sigma_i^2 \right),
\]

whence:

\[
\Delta \sigma_i^2 = \frac{\sigma_m^2 - \sigma_{\text{min}}^2}{\sum_{i=1}^{n} i}.
\]

It makes sense to consider only nondecreasing sequences \( \{ \sigma_i \} \), wherein \( \Delta \sigma_i^2 \geq 0 \). That is why parameter \( \sigma_{\text{min}}^2 \) may take values from the interval with borders 0 and \( \sigma_m^2 \), wherein case of \( \sigma_{\text{min}}^2 = \sigma_m^2 \) mixed sample is a sample of normally distributed errors with variance \( \sigma_m^2 \).

Considered density of distribution of errors of navigational measurement is the true density of distribution of mixed sample random values \( f_s(x) \), and supposed density \( \varphi(x) \) is the density of normal distribution with variance \( \sigma_m^2 \).

To define the efficiency value of the ship’s observed coordinates obtained using the least-square method in presence of surplus measurements we will find improper integrals \( q_s, p_i \) and \( s_i \) [2].

Improper integral \( q_s \) depends on supposed normal distribution \( \varphi(x) \) [2]:

\[
q_s = \int \limits_{\tilde{x}_i} f_s(x) \left\{ \frac{\partial^2 \varphi(x)}{\partial x^2} \varphi(x) - \left[ \frac{\partial \varphi(x)}{\partial x} \right]^2 \varphi(x) \right\} dx = -\frac{1}{\sigma_m^2}.
\]

In its turn, improper integral [2]:
Improper integral [2]:

\[ p_s = \int f_s(x) \left( \frac{\partial}{\partial x} \frac{\varphi(x)}{\varphi(x)} \right)^2 \, dx = \int \frac{x^2}{\sigma_i^m f_s(x)} \, dx = \frac{1}{\sigma_i^m} \sum_{i=1}^{n} p_i \sigma_i^2. \]

Taking into account obtained expressions for improper integrals \( q_s, p_s \) and \( s_s \) efficiency [3]:

\[ e = \frac{q_s^2}{p_s s_s} = \frac{1}{\sigma_i^m} \sum_{i=1}^{n} p_i \sigma_i^2 \frac{1}{\sqrt{2\pi}} \int \frac{x^2}{\sigma_i^m} \, dx = \frac{1}{\sigma_i^m} \sum_{i=1}^{n} p_i \exp \left( -\frac{x^2}{2\sigma_i^2} \right) \]

or

\[ e = \frac{1}{\sigma_i^m} \frac{1}{\sqrt{2\pi}} \int \frac{x^2}{\sigma_i^m} \, dx = \frac{1}{\sigma_i^m} \frac{1}{\sqrt{2\pi}} \int \frac{x^2}{\sigma_i^m} \, dx = \frac{1}{\sigma_i^m} \frac{1}{\sqrt{2\pi}} \int \frac{x^2}{\sigma_i^m} \, dx. \] (6)

With the help of expression (6) values of efficiency for values \( n \) from 2 to 30 and for three variants of sequence alteration have been found \{\( p_i \)\}: increasing, constant and decreasing (accordingly variants 1, 2 and 3). The results that have been obtained are presented in Table 1.

<table>
<thead>
<tr>
<th>Number of making up samples</th>
<th>( {p_i} )</th>
<th>Number of making up samples</th>
<th>( {p_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.993</td>
<td>1</td>
<td>0.979</td>
</tr>
<tr>
<td>3</td>
<td>0.987</td>
<td>0.971</td>
<td>0.983</td>
</tr>
<tr>
<td>4</td>
<td>0.984</td>
<td>0.957</td>
<td>0.962</td>
</tr>
<tr>
<td>5</td>
<td>0.982</td>
<td>0.945</td>
<td>0.944</td>
</tr>
<tr>
<td>6</td>
<td>0.980</td>
<td>0.934</td>
<td>0.928</td>
</tr>
<tr>
<td>7</td>
<td>0.980</td>
<td>0.926</td>
<td>0.915</td>
</tr>
<tr>
<td>8</td>
<td>0.979</td>
<td>0.918</td>
<td>0.903</td>
</tr>
</tbody>
</table>

3. Conclusions

Reducing of observed coordinates accuracy up to 10% takes place where efficiency value equals 0.909. The analysis of Table 1 shows that in the case where \( n \) is lesser than 8, the reduction of observation accuracy is less than 10%. Upon the implementation of the first variant of sequence \( \{p_i\} \) reduction of accuracy is not greater than 2% irrespective of value \( n \).

In the terms indicated above calculation of observed coordinates using the least-square method is possible with using surplus measurements.

Thus, the evaluation of the ship’s coordinates efficiency has been obtained and calculated by the least-square method in case of mixed distribution of errors of navigational measurements sample for three possible variants of
sequences \{p_i\} and number of making up samples to 30.

References

Implementation of Railway Infrastructure Visualization Using Data Collected in railML

T. Ciszewski¹, W. Nowakowski², Z. Łukasik³

¹Kazimierz Pulaski University of Technology and Humanities in Radom, Maleczewskiego 29, 26-600 Radom, Poland, E-mail: t.ciszewski@uthrad.pl
²Kazimierz Pulaski University of Technology and Humanities in Radom, Maleczewskiego 29, 26-600 Radom, Poland, E-mail: w.nowakowski@uthrad.pl
³Kazimierz Pulaski University of Technology and Humanities in Radom, Maleczewskiego 29, 26-600 Radom, Poland, E-mail: z.lukasik@uthrad.pl

Abstract

The development of rail transport is largely based on modern IT solutions, including specialized computer software. Unfortunately, the exchange of data between various IT environments requires the creation and maintenance of system interfaces. That is why the initiative to develop a uniform data exchange standard for rail applications called railML is very valuable. The authors of the paper, inspired by this technology, have developed a computer program that allows visualization of information about the railway infrastructure acquired from railML databases on maps. These activities are in line with the needs of developing IT tools supporting railML.

KEY WORDS: railML, RailTopoModel, railway infrastructure, visualization, railVIVID

1. Introduction

The development of rail transport is largely determined by the implementation of modern information and communication technologies [6, 10, 11, 13, 16]. Unfortunately, the multitude of these solutions and, at the same time, large deficiencies in the standardization of data representation mechanisms and their exchange force the need to design multiple interfaces, whose task is to ensure data exchange between cooperating systems [9, 12, 14, 22]. It is associated not only with incurring specific expenditures on their development, but also with updating resulting from system changes. Therefore, in 2002, on the initiative of a group of scientists from the German Fraunhofer Institute for Transport Systems and Infrastructure in Dresden and the Swiss Federal Institute of Technology of the Institute for Planning and Transport Systems, the first RailML (Railway Markup Language) open standard specification for railway applications was created [2-5, 12, 15].

At the same time, an abstract railway infrastructure data model defined in the UIC IRS 30100 standard (RailTopoModel, RTM) was developed [1, 7, 18, 20, 21]. It should be emphasized that the latest railML specification (version 3.1) complies with the above standard. The railML is based on the XML (Extensible Markup Language) standard, which has been designed by the W3C (World Wide Web Consortium) as the meta-language for data description [8, 19]. Due to the features of the XML standard, which have all its implementations, railML enables data storage along with a description of their structure, which is extremely effective. Previous versions of railML, including version 2.4, allowed IT railway systems to store and exchange data on rolling stock, railway traffic management, stacking timetables, information for the passenger as well as booking and selling tickets. The latest version of this standard also includes the <interlocking> sub-scheme for describing railway dependencies.

To define the content of the document the railML uses a hierarchical tree structure, in which the root is the <railml> tag. It is the parent for all internal elements (children). Each such element may contain predefined attributes to provide a more accurate description. In the current railML versions the following four main types of elements have been distinguished: <infrastructure>, <rollingstock>, <timetable> and <interlocking>. The authors of the paper have developed software that allows us to view and edit railML files including the latest version 3.1, as well as to visualise information about railway infrastructure on Google Maps.

2. RailVIVID

The popularization of the railML standard largely depends on the development of IT tools supporting this project. Currently, there are several applications with the implementation of the railML standard. One of them is railVIVID, which was developed in 2015 as a project of UIC and railML.org and made available under a freeware license [3]. The main purpose of the program is to verify and visualize railML data in version 2.x or later. RailVIVID allows us to validate railML files syntax and does not require railML and XML syntax knowledge from program users. In addition, the user can visualize the infrastructure, the timetable and the rolling stock elements with the help of graphic tools. An example of such visualization is shown in Fig. 1.
There are five tabs in the main window of the railVIVID:

- **Validator**, which allows to validate correctness of the railML syntax;
- **Infrastructure**, that allows to display the "infrastructure" data in a geographical and topological view;
- **Timetable**, which allows to display the "timetable" data in a graphical and tabular view;
- **Vehicles**, that allows to display the "rolling stock" data;
- **Interlocking**: the option is currently disabled.

After selecting one of the tabs, the user is asked to perform additional configuration. For example, in the "Infrastructure" tab, the data selection "by track", "by operational point" or "by net" is available as well the map provider configuration ("Google Maps" or "OpenStreetMap", none) is possible.

### 3. RailML Editor & Viewer

The authors of the paper, recognizing the need to support the railML popularization initiative, have developed the proprietary "railML Editor & Viewer" tool dedicated to this standard [7]. Currently, this software allows to view and edit railML files, as well as visualize some railML data. In order to present the functionality of this software, a sample of railML data structure provided by railML.org [17] was used. The file contains data for 108.4 km of double- and single-track line being a part of the Middle Rhine Track Network of the German Infrastructure manager DB Netz’ lines containing the following lines:

- Line 3510: Bingen (Rhein) Hbf [FBGK] – Mainz Hbf [FMZ];
- Line 2630: Koblenz Hbf [KKO] – Bingen (Rhein) Hbf [FBGK];
- Line 3511: Bingen (Rhein) Hbf [FBGK] – Bad Kreuznach [SBKN].

An overview map (whose data stored in the railML file was used for further analysis) of the railway lines (3510, 2630, 3511) was shown in Fig. 2.
As already mentioned, the functionality of the "railML Editor & Viewer" includes convenient preview of railML files. The railML file opened in the main application window is shown in Fig. 3. The data is displayed in the "Source" panel, and the structure in the "Tree" view. The "Attribute" and "Value" boxes are automatically updated after selecting fields in railML tree.

The option "Edit" should be selected from the menu to enter railML edit mode. In this mode the "Tree", "Attribute" and "Value" panels are hidden and railML file can be edited. The "Search" and "Mark" options may be helpful (Fig. 4). Before saving the file, the syntax validation is performed and errors, if any, are indicated.

The last of the functionalities realized by the "railML Editor & Viewer" application is the visualization of railway infrastructure elements. The visualization data is acquired from railML file. To perform this action the user must select the "View->Infrastructure" option from the menu. Currently the software has implemented the function of visualizing only infrastructure data and use "Google Maps" service as a map provider.

The sample visualizations of selected infrastructure elements on a digital map are presented in Fig. 5 and Fig. 6.
Further development of the "railML Editor & Viewer" application will concern the implementation of visualization functionality for Timetable and Rolling Stock elements as well as improvement in Infrastructure elements visualization.

4. Conclusions

A certain barrier in the development of IT systems dedicated to the railway industry is the mutual incompatibility of solutions proposed by individual manufacturers. This entails the need for intensive and expensive development of interfaces to enable collaboration between railway IT systems. Therefore, initiatives such as railML that allow for the standardisation in this area of technology should be considered as very important. The more that the proposed solution together with RailTopoModel, is part of the effort to develop complete standards for modelling topology and describing railway infrastructure. The result of these efforts is a systematic increase in the number of software tools supporting railML. This is undoubtedly due to the fact that it is much easier to ensure software compatibility, unify data structures
and provide the best possible technical interoperability when we use the standardized data model and its flexible implementation in form of railML.

The authors of the paper, inspired by this technology, have been developing for some time proprietary software "railML Editor & Viewer", which combines the functionality of previewing, editing, validating railML files, as well as visualizing infrastructure data on "Google Maps". In the future it is also planned to include visualization for further elements defined in railML. These actions are intended to test the suitability of the proposed standard to store and process data in railway applications. At the same time, it is an attempt to support this technology by developing useful software tools operating directly on railML files.

References

1. Augele, V. 2017. Comparative Analysis of Building Information Modelling (BIM) and RailTopoModel/railML in View of Their Application to Operationally Relevant Railway Infrastructure. Project Paper in the Field of Intelligent Transportation Systems, Technical University of Dresden, Germany.
Results of the Experimental Research of the Medium Speed Diesel Engine Work on Soybean Oil

I. Shvets¹, O. Hrabovenko², S. Dotsenko³, V. Nesterenko⁴

¹Pervomaisk Branch of Admiral Makarov National University of Shipbuilding, Pervomaisk, Ukraine, Odeska 107a, 55214 Pervomaisk, Ukraine, E-mail: sheva_pm@ukr.net
²Pervomaisk Branch of Admiral Makarov National University of Shipbuilding, Pervomaisk, Ukraine, Odeska 107a, 55214 Pervomaisk, Ukraine, E-mail: goi70@ukr.net
³Pervomaisk Branch of Admiral Makarov National University of Shipbuilding, Pervomaisk, Ukraine, Odeska 107a, 55214 Pervomaisk, Ukraine, E-mail: dotsenosm2016@gmail.com
⁴Pervomaisk Branch of Admiral Makarov National University of Shipbuilding, Pervomaisk, Ukraine, Odeska 107a, 55214 Pervomaisk, Ukraine, E-mail: vik6462@ukr.net

Abstract

The use of alternative fuels derived from oil of plant and animal origin in internal combustion engines gives an opportunity not only to reduce consumer’s fuel dependence on the use of petroleum fuels, but also significantly increases the environmental performance of the power plant by reducing toxic components in the exhaust gases. The comparative analysis of the results of the experimental research of the output parameters of the medium speed diesel engine operating according to the load characteristic when using diesel fuel and soybean oil has been performed in the article. The object of the experimental research is a six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm) with direct injection of fuel into the cylinder, gas turbine charging and intermediate cooling of boost air. In the process of the research, the technical and economic parameters of the engine and exhaust gas toxicity indicators when working on diesel fuel and soybean oil have been determined. The comparison of obtained indicators has shown that the combustion process when using plant oil is delayed in time and, as a result, the efficiency of the working cycle is reduced. Therefore, there is a need to improve it.

KEY WORDS: medium speed diesel engine; soybean oil; diesel fuel, maximum pressure; temperature of exhaust gases, emissions of toxic components

1. Introduction

Internal combustion engines (ICEs) have been and continue to be the main consumers of petroleum fuels. Moreover, diesel engines, due to their greater efficiency compared to petrol engines, and the ability to consume a wider range of liquid fuels, comprise of a higher proportion in installations of various purposes. In modern conditions, when there are processes of price instability due to oil price seasonal fluctuations in the market of petroleum products, the issue of using alternative fuels (liquid fuels of non-petroleum origin) which are not inferior to petroleum fuels in their physicochemical and operational properties, remains relevant. In particular, consumers should have access to renewable raw materials for their extraction and processing, this will give an opportunity to choose the most economical option for obtaining a unit of energy. The main requirements and prospects for the use of vegetable fuels in internal combustion engines have been represented in the article [1].

The advantages of using such fuels are significant, because they provide consumers with ample opportunities for the power plant operation. Examples of such advantages include the ability to independently select raw materials for utilization and processing into fuel, the ability to reproduce raw materials and accumulate their reserves through the use of agriculture and enterprises for processing products and secondary raw materials, the ability to independently form the price per kilowatt of energy, no need for replacement the internal combustion engine power plant for a new, relatively low cost of the fuel system modernization and many others. Separately, it should be noted a significant improvement in the environmental performance of the power plant running on fuels of vegetable origin, although the parameters of economy and efficiency in this case have to be sacrificed.

However, the use of fuels based on vegetable oils in the internal combustion engine has not only advantages, but also contains a number of problems, the main of which is the preparation of this fuel before it is fed into the diesel cylinder. A significant difference in the physicochemical properties of vegetable and petroleum fuels under the same initial conditions (environmental conditions) make it impossible to further start and operate the diesel engine. Therefore, the essential requirement for the use of fuels of vegetable origin is the implementation of a set of measures for fuel preparation, which are aimed to ensure the normal and reliable operation of fuel equipment and diesel engine in general. Failure to fully comply with this requirement entails the violation of the nature of injection, mixing and combustion processes of the fuel-air mixture and with them the reduction of the efficiency of the diesel cycle and related environmental parameters of the internal combustion engine.

The comparative analysis of parameters of the working cycle of the medium-rotating engine received during the
experimental research when working on soybean oil and diesel fuel has been carried out in the presented work. The analysis has been performed through the use of the differentiated method, with the help of comparing the corresponding parameters of the engine duty cycle under the same load conditions of the power plant, but when working on different fuels.

The analysis of previous publications and research has shown that the use of soybean oil as a fuel improves engines’ fuel-economic and environmental performance [1, 2].

Given the peculiarities of the chemical composition of fuels from vegetable oils, and operational problems that arise when using them, recently more and more attention is paid to the use of fuel mixtures based on a significant proportion of diesel fuel and vegetable oil or its modification, which is proved in such works as [5, 6].

It is obvious that the performance cycle, economy and toxicity depend not only on the physicochemical properties of the fuel, but also on the design, control and operational parameters of the diesel engine, load mode, workflow characteristics, soybean oil composition and level of dispersion during injection.

The process of dispersion of a jet of plant fuel into droplets and blisters has differences in comparison with a similar dispersion of a jet of diesel fuel. Influence on the dispersion process is determined by such indicators as: density, viscosity, surface tension force, fuel elasticity and other physicochemical properties of the fuel. Influencing the process of droplet formation when spraying fuel, the nature of the processes of injection, mixing, heating and evaporation of fuel changes [3, 4, 6], which ultimately affects the combustion of fuel in a diesel engine.

Therefore, taking in consideration the above-mentioned facts, the processes of injection, spraying, mixing and combustion of medium-speed diesel when working on soybean oil and its mixtures of diesel fuel in different percentages have been defined for the research.

2. The Main Principal

The peculiarity of the diesel fuel system of the medium speed diesel engine proposed during the experimental research is that it is flow-type (see Fig. 1) and ensures the operation of the diesel engine on both diesel fuel and vegetable oil. When the diesel engine is running on diesel fuel, the diesel fuel is fed by gravity from the supply tank (20) through the fine filter (9) to the fuel pumps (3). When working on vegetable oil, the fuel is preheated to a temperature of 70 - 75°C in the fuel preparation system before being fed into the diesel fuel system, which consists of a supply tank of vegetable oil (12), an electric boiler (13), a water pump (16), an expansion tank (17), a vegetable oil supply pump (14) with a pressure reducing valve (5), a fuel supply pump to the supply tank (15). The fuel in the supply tank (12) is heated by water, which is heated in the electric boiler (13) and supplied by the circulating water pump (16) to the tank coil.

Fig. 1 Schematic diagram of the diesel fuel system when working on vegetable oil: 1 - fuel pump; 2 - cooling nozzle; 3 - high-pressure fuel pump; 4 - strainer; 5 - pressure reducing valve; 6 - fuel cooler; 7 - unload valve; 8 - throttle plate; 9 - fine fuel filter; 10 - temperature controller; 11 - receiver; 12 - supply tank of vegetable oil; 13 - electric boiler; 14 - vegetable oil supply pump; 15 - fuel supply pump to the supply tank; 16 - water pump; 17 - expansion tank; 18 - thermometer; 19 - shut-off valve; 20 - supply tank of diesel fuel

Thermometers (18) are installed on the bodies of the supply tank (12) and the boiler (13) to control the temperature of water and fuel. The mode of operation of the fuel system and fuel preparation system is regulated by
shut-off valves (19). The fuel that has been heated and filtered in the fuel preparation system is supplied by the pump (14) to the engine and through the fine fuel filter (9) enters the main fuel network to the high-pressure fuel pumps (3) and from the fuel network returns back to the fuel tank (12). In accordance with the order of operation of the cylinders, the high-pressure tubes of high-pressure fuel pumps supply a measured amount of fuel to the cooling nozzles (2). The amount of fuel and the pressure at which the fuel is fed into the nozzles is determined by the mode of operation of the diesel engine; the excess fuel from the nozzles is collected in the collector of fuel leak and is also sent to the fuel tank.

To maintain the required pressure in the main fuel network, the throttle plate (8) with a hole with a diameter of 1 mm is installed on the fuel return pipe in the flow tank.

To protect against increased fuel pressure on the fuel injection pump for cooling the nozzles (1), the pressure reducing valve (5) is adjusted to the pressure of 0.3 MPa.

Diesel fuel for cooling the nozzles is taken from a separate fuel tank mounted on the exposed face of the diesel engine. After cooling the nozzles, the fuel through the temperature controller (10) and the fuel cooler (6) enters the inlet of the fuel pump (1). The throttle plate (8) with a hole with the diameter of 1 mm is installed to create a support at the outlet of the fuel manifold from the nozzles. Diesel fuel for the cooling nozzles circulates in a closed loop.

3. Test Bed and Experimental Results

The experimental research to determine the effective performance of diesel fuel and soybean oil have been carried out on a six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm), which is a part of a stationary diesel generator. The specified diesel engine is a four-stroke, liquid-cooled, with an open combustion chamber of the Hesselman type, gas turbine supercharging and intermediate cooling of supercharged air.

Tests of diesel generators (diesel-generator unit - DGU) DGU-900 and DGU-800 (Fig. 2) have been carried out at the enterprise "Pervomaiskdieselmash", according to such parameters as: for DGU-900 nominal power was 900 kW at the crankshaft speed of 750 rpm and use of unrefined soybean oil as fuel; for DGU-800 nominal power was 800 kW at the crankshaft speed of 750 rpm and use of diesel fuel.

The purpose of the first test was to determine the specific fuel consumption during operation of the diesel generator on soybean oil. The parameters of DGU-900 were measured at the modes corresponding to 25, 50, 75 and 100% of the nominal power of the diesel generator. The load was set by active resistances and parallel operation with the electric power system.

For testing on diesel fuel, the load modes of DGU-800 were identical to the output mode of rated power of 800 kW. Thus, the test using diesel fuel was to provide experimental material for further analysis and comparison of the results of two experiments.

Measurements of soybean oil and diesel fuel consumption were performed by weight. However, the diesel generator for work on soybean oil was equipped with a soybean oil heating unit (Fig. 3). Heated soybean oil was poured into a consumable container, which was installed on the floor electronic scales (VN-300-1 type) with a measuring range of 0-300 kg. On the specified loading modes, the time of consumption by the diesel generator of a portion of fuel weighing 5 kg was fixed.
The obtained results of DGU-900 when working on soybean oil and DGU-800 when working on diesel fuel (Table 1) have been presented in Fig. 4 and Fig. 5. In the course of the research, both standard and additional control and measuring devices were used, which were calibrated and meet the current standards.

### Table 1

<table>
<thead>
<tr>
<th>The name of indicators</th>
<th>Diesel fuel</th>
<th>Soybean oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at a temperature of 15°C, kg/m³</td>
<td>829</td>
<td>920</td>
</tr>
<tr>
<td>Lower calorific value of the fuel, kJ/kg</td>
<td>42500</td>
<td>37050</td>
</tr>
<tr>
<td>Kinematic viscosity mm²/s (at 15°C)</td>
<td>4.0</td>
<td>57.5</td>
</tr>
<tr>
<td>Dynamic viscosity (mPa s) (at 15°C)</td>
<td>1.32</td>
<td>56.4</td>
</tr>
<tr>
<td>Inflammation temperature in °C</td>
<td>70</td>
<td>312</td>
</tr>
</tbody>
</table>

**Results of the experimental studies.** The analysis of the processed test protocols and diagrams (Fig. 4 and Fig. 5) shows that at the power of 800 kW and working on soybean oil, the maximum combustion pressure in absolute terms was 12.7% lower than working on identical load mode, but working on diesel fuel. The specific effective fuel consumption when working on soybean oil and power of 903 kW was 252 g/kWh.

![Fig. 4 Load characteristics of the six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm) when working on diesel fuel and soybean oil. a – dependence of the maximum pressure (MPa) in the cylinder on loading; b – dependence of the average temperature (°C) of exhaust gases behind the cylinder(s) on loading; ](image)

- diesel fuel (P = 800 kW; N = 750 rpm);
- soybean oil (P = 900 kW; N = 750 rpm);

![Fig. 5 Load characteristics of the six-cylinder, four-stroke supercharged medium speed diesel engine (26 – the diameter of the cylinder, cm; 34 – the piston stroke, cm) when working on diesel fuel and soybean oil. a – dependence of specific effective fuel consumption (g / (kW h)) on loading; b – Dependence of the coefficient of excess air on the loading; ](image)

- diesel fuel (P = 800 kW; N = 750 rpm);
- soybean oil (P = 900 kW; N = 750 rpm)

The temperature of the exhaust gases behind the cylinders when working on soybean oil and the mode of 800 kW is 13% higher than working on diesel fuel, the difference is approximately 60-70°C. This indicates that the combustion process is delayed in time when working on soybean oil compared to diesel fuel, which has affected the
toxicity of exhaust gases. Thus, the concentration of NOx in the entire load range of the diesel engine from 230 to 903 kW when working on soybean oil has ranged from 1276 to 1409 ppm.

The comparative analysis of the results has shown that with lower heat of combustion and worse combustion conditions of soybean oil than diesel fuel, the specific effective fuel consumption is higher by 12.9% for vegetable oil than when working on diesel fuel. Thus, obtaining the power required by consumers needs the increase of the cyclic fuel supply, which will inevitably lead to the increase in the maximum injection pressure, which is not desirable from the point of view of reliable operation of the internal combustion engine.

The difference in fuel density, where soybean oil is 9% higher than diesel fuel, will affect the injection parameters. First of all, this factor applies to increasing the range of the fuel jet of flame and reducing the cone of its disintegration. The difference in viscosity and surface tension force for soybean oil and diesel fuel will increase the number of droplets of large diameter when disintegrating, and in accordance with the delay of their heating and evaporation, and at the same time combustion.

The coefficient of excess air when working on soybean oil (800 kW mode) is 5% higher than when working on diesel fuel, which is the result of the need for better air supply of the combustion process when using vegetable oil as fuel.

Thus, the results of the experimental research allowed to compare the efficiency of soybean oil and diesel fuel under identical conditions of diesel engine loading and to draw conclusions about the prospects for the use of fuels from vegetable oils in the medium-rotating engine.

4. Conclusions

The conducted experimental research of the medium-rotating engine gave an opportunity to determine the parameters of the working cycle, economy and environmental safety when using fuel from soybean oil.

The use of soybean oil in the medium-rotating engine with the smaller value of lower heat of combustion than in diesel fuel leads to the increase in the specific effective fuel consumption by 13%.

Physicochemical properties of soybean oil affect the processes of injection and mixing, and as a result, the combustion process is delayed. The study of the processes of disintegrating a jet of fuel from soybean oil should be included in the further experimental research.

References

Corrosive Wear of Materials Used in Special Mobile Equipment

J. Stodola¹, J. Jelinek², A. Breznicka³, Z. Krobot⁴, P. Stodola⁵

¹University of Defence, Kounicova Str. 65, 662 10 Brno, Czech Republic, E-mail: jiri.stodola@unob.cz
²University of Defence, Kounicova Str. 65, 662 10 Brno, Czech Republic, E-mail: josef.jelinek@unob.cz
³Alexander Dubcek University of Trencin, Pri parku Str. 19, 911 06 Trencin, Slovak Republic, E-mail: alena.breznicka@tnuni.sk
⁴University of Defence, Kounicova Str. 65, 662 10 Brno, Czech Republic, E-mail: zdenek.krobot@unob.cz
⁵University of Defence, Kounicova Str. 65, 662 10 Brno, Czech Republic, E-mail: petr.stodola@unob.cz

Abstract

The paper analyzes the corrosion wear of materials of typical components in special mobile equipment (vehicles); the results were obtained by long-term research into the problem of machine parts degradation. The authors analyzed selected corrosion mechanisms and conditions under which corrosion takes place. Practical applications are focused on corrosion testing of two selected steels in salt fog. The results show the percentage of corrosion on the surface of the test materials and the corrosion loss of the materials. Obtained information is important for predicting corrosion wear in time and given environmental conditions, which is used in practice for long-term storage of special vehicles, their groups and spare parts.

KEY WORDS: corrosion wear, degradation process and testing, material of special mobile vehicles, corrosion rate and material loss

1. Introduction

Wear processes are inevitable, but undesirable throughout the life cycle of the equipment [11-12], as they lead to massive degradation of materials, which often results in failure or even an accident. We try to prevent these phenomena systematically and to increase operational reliability and service life of the equipment. Specific requirements are placed on special vehicles during a relatively long and diverse life cycle. This equipment is operated under extreme conditions (weather, off-road, time, operational, maintenance, storage, with varying degrees of load or no load, etc.) for a relatively long time (up to 30 years and sometimes even more) and during this time, full utilization alternates with partial or no utilization. Corrosion is one of the most important wear processes. In developed countries, the damage caused by corrosion is estimated at 3 to 6% of GDP. In the Czech Republic, corrosion causes nearly € 5.2 billion of damage annually. Corrosion means the destruction of metals, but also of non-metals, organic and even inorganic materials due to their chemical, electrochemical, or microbial and biological reactions with the environment [1]. Corrosion of ferrous metals can be classified according to oxygen participation in the ongoing process, namely aerobic (with oxygen) and anaerobic (without oxygen). Corrosion occurs in the atmosphere, in gases, in water and other liquids, in soils and in various chemicals that are in contact with the corroding element.

Metals are the main material of special mobile equipment, which is why they have received increased attention. The so-called corrosion process factors have a fundamental influence on the corrosion process; they are divided into external (ambient, pollution, temperature, humidity, pressure, exposure time etc.) and internal ones (type and structure of material, chemical composition, production technology, machining etc.). The aim of the research was to investigate the course of corrosion wear of selected materials used in special equipment, modelling of corrosion wear and analysis of the corrosion wear process.

2. Corrosion Wear

Almost all materials that are in contact with the environment are subject to corrosive degradation by chemical, physical and/or biological influences. Most metals and their alloys are thermodynamically unstable and can spontaneously change into an oxidized state. Thermodynamic stability is determined by the change in Gibbs energy $\Delta G$, that is given by

$$\Delta G = \Delta H - T \cdot \Delta S,$$  

where $\Delta H$ – enthalpy change (stored energy in the given system) [J]; $T$ – thermodynamic temperature [K]; $\Delta S$ – entropy change (system uncertainty) [J·K$^{-1}$], in the equation:

$$H = U + p \cdot V,$$  

where $\Delta H$ – enthalpy change (stored energy in the system) [J]; $U$ – internal energy of the system [J]; $p$ – pressure [Pa]; $V$ – volume [m$^3$].
Gibbs energy (thermodynamic change or chemical potential) is the energy that 1 mole of a compound receives or delivers into the environment at its origin at constant temperature and pressure values. The Gibbs energy enables the spontaneous process of feasibility of the action, the following applies: \( \Delta G = 0 \) the system is in equilibrium; \( \Delta G > 0 \) the process does not occur spontaneously; \( \Delta G < 0 \) the process occurs spontaneously; at the same time, the system is trying to spontaneously reach an equilibrium state and these transitions, e.g. in metals, are accompanied by the formation of corrosive fumes. Corrosion is generally manifested in many ways, e.g. uniform, Fig. 1 [2], selective or uneven material loss, corrosion pits, crevices, pitting, Fig. 2, holes, cracks, fractures, intercrystalline or transcrystalline corrosion, hydrogen, biological, vibration, fatigue, erosion corrosion, etc. An example of corrosion wear of a combustion engine cylinder liner is shown in Fig. 3[1].

**Fig. 1 Example of uniform corrosion**

**Fig. 2 Example of pitting corrosion**

**Fig. 3 Corrosive wear of combustion engine cylinder liner**

**Chemical corrosion**

Chemical corrosion occurs in non-conductive environments (non-electrolytes, gases); it is caused by thermodynamic instability associated with the transition of the metal to a more stable state. A spontaneous process occurs when the difference in free enthalpy (energies) is negative and energy is released. Chemical corrosion occurs in oxidizing or reducing environments. Metal oxidation is a complex process that takes place at the phase boundaries of the metal - oxide - oxygen system environment and in the formed oxide layer [3]. The whole process begins with the surface absorption of the oxidizing component, which produces an ionic bond between the oxygen and the metal surface atoms. The metal gives two electrons to the oxygen atom and the bond is different from that of the oxygen and metal in the oxide. The oxygen absorption activity depends on the spatial parameters of the material surface (edges, protrusions, radii, etc.). Absorption is affected by nonspecific forces with low binding energy (Van der Vals), which is a reversible process, and chemisorption, where chemically absorbed \( O_2 \) particles are strongly bound to the surface by a bond similar to chemical bonding, which is an irreversible process [4]. The corrosion process ends by the formation of oxide layer or other chemical reaction products. The next process is determined by the properties of the oxidation layers. The rate of oxidation then depends on the properties of the layers where the slowest diffusion reaction takes place. Chemical corrosion is influenced by various factors, the most important of which is temperature (heating mode, temperature changes and their fluctuations, temperature hold, temperature shocks, etc.), which massively affects oxidation kinetics, properties of oxidized layers, chemical reaction rate and diffusion rate. For example temperature fluctuations during cyclic heating and cooling results in massive destruction of the oxidation layers due to different thermal expansion and internal stress. The oxidation rate in this case is almost linear. Another factor is the mechanical properties of the oxidation layers, in which tensile or compressive stresses are created, causing destruction of these layers [5]. The destruction occurs at certain dimensions of the layer, which is dependent on the adhesion of the oxidation layer to the metal, the cohesive forces in the layer and their relationship to the internal stress. At low adhesion or cohesion, the layer separates from the surface, further oxidation and microcavities, etc. occur. Chemical composition of the gas also influences the kinetics of oxidation. The chemical composition of the oxidizing medium is significantly related to the thermodynamics of the corrosion process and to temperature. \( SO_2 \) and other gaseous sulphur compounds, hydroxyl group \( OH \), \( NO_2 \), water vapour, \( CO_2 \), etc. are very aggressive.

**Electrochemical corrosion**

The basic principle of electrochemical corrosion is the formation of local electrical cells. Their formation is associated with different electrochemical potentials in the interaction of two different metals. The basis for chemical corrosion is the thermodynamic instability of the metal in the environment. Due to anodic reaction (oxidation process in
which the positive charge of the metal is transferred to the electrolyte), the corroding metal loses its metallic character and becomes a cation (positively charged ion - atom or molecule) [3], which dissolves in the solution, or becomes an insoluble compound. By changing the electric charge, the anodic reaction (dissolution) is closely connected to the cathodic reaction (by transferring a negative charge of the metal to the electrolyte), which is a reduction process. The corrosion rate is then proportional to the magnitude of the current flowing through the corrosion cell between the anode and cathode. The anodic action is connected with the release of electrons, e.g. \( \text{Fe} \rightarrow \text{Fe}^{2+} + 2e^- \). For this reaction to take place, the cathode process must be associated with the ongoing reduction of the depolarizer, which will absorb the electrons released by the oxidation event. In the absence of a depolarization reaction, the anodic dissolution reaction could not occur. During electrochemical corrosion on the metal surface, the oxygen dissolved in water \( \text{O}_2 + 4e^- + 2\text{H}_2\text{O} \rightarrow 4\text{OH}^- \) or hydrogen cations e.g. \( 2\text{H}^+ + 2e^- \rightarrow \text{H}_2 \) are reduced.

The electrode potential characterizes the energy continuity (potential difference) between the positive and negative parts of electrodes surface. A potential difference (electromotive voltage of the galvanic cell) is created between the metal surfaces immersed in the electrolyte (solutions conducting electric current). The potential difference arises in the electric double layer of the so-called half-cell. The half-cell is an electrode immersed in the electrolyte. Between the surface of the metal and the electrolyte, particles and charges are exchanged. The metal atoms are released from the metal bond and leave one or more electrons in the metal and pass into the solution in the form of cations. Conversely, the electrolyte cations take up the necessary number of electrons on the metal surface, are reduced and incorporated into the crystalline metal lattice. Both of these phenomena are reversible. However, irreversible processes predominate in corrosion processes, which makes it possible to assess the corrosion resistance of metals on the basis of electrochemical potentials [6, 7]. Higher potential means less metal susceptibility to corrosion (noble metals) and vice versa. A thin layer of corrosive fumes on the surface alters the potential of the metal and gives it some protection – this phenomenon is called passivity [8].

Electrochemical corrosion is influenced by internal and external factors. The internal factors include the location of the respective metal in the periodic table of elements, surface treatment, load and stress, metal structure, etc. External factors include pH (hydrogen exponent = potential of hydrogen), salt concentration in the solution, content of corrosion inhibitors or stimulators, temperature, pressure, ultrasound, radioactive radiation, etc.

### 3. Corrosion Tests

According to [9, 10], a corrosion test was carried out in the corrosion chamber, Fig. 4, in a salt fog of a neutral sodium chloride solution with a density of 1,930 kg m\(^{-3}\), pH between 6.7 and 7.2 and temperatures of 35°C and 50°C, sample hardness according to Vickers 155 HV10. Ten samples of steel EN C22R, size 100 × 50 mm (area 0.005 m\(^2\)), thickness 2 mm, roughness \( R_a = 1.3 \mu m \) and ten samples of weldable steel EN 10131, hardness according to Vickers 138 HV10 were used for the test. The standard and actual chemical composition of both steels is shown in Table 1.

**Note:** All corrosion test results for individual samples of both materials are reported as arithmetic means.

Three basic criteria were chosen to evaluate the test, namely the percentage of corrosion on the sample surface (accuracy 5%), weight loss and macroscopic evaluation of the sample surface. The percentage of corrosion was evaluated by digital recording of the sample surface and subsequent software evaluation. The corrosion rate was calculated from the weight loss by accurate weighing before and after the test. The weight loss is the main parameter of corrosion degradation of material [2].

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>C</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN C22R</td>
<td>0.226</td>
<td>0.379</td>
<td>0.020</td>
<td>0.040</td>
<td>0.450</td>
<td>0.210</td>
<td>0.057</td>
<td>0.102</td>
</tr>
<tr>
<td>EN 10131</td>
<td>0.200</td>
<td>0.007</td>
<td>0.017</td>
<td>0.016</td>
<td>0.686</td>
<td>0.005</td>
<td>0.009</td>
<td>0.003</td>
</tr>
</tbody>
</table>

![Fig. 4 Corrosion chamber S 400 M TR](image1)

![Fig. 5 Sample surface after corrosion test](image2)

Time dependence of the corrosion rate was solved as a function of the ratio increase of corroded sample surface to its weight and exposure time. We calculate the weight corrosion loss according to the equations:
where \( K, U \) – corrosion weight loss per corroded surface in \([\text{g} \cdot \text{m}^{-2}]\), or area loss (for even corrosion) in \([\text{mm}]\); \( \Delta m \) – difference in weight of the test sample before and after the test \([\text{g}]\); \( S_{vz} \) – sample area where corrosion takes place \([\text{m}^2]\); \( \rho \) – material density \([\text{kg} \cdot \text{m}^3]\).

The rate of corrosion is determined from weight loss, then:

\[
v_k = K \cdot \frac{365}{t},
\]

or

\[
v_k = \frac{U \cdot 365}{t},
\]

\[
V = \frac{U \cdot 365}{\rho},
\]

\[
v = \frac{V}{\tau},
\]

\[
v_k = \frac{S_{vz} \cdot h_r}{\tau},
\]

where \( v_k \) – corrosion rate in \([\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}]\) or in \([\text{mm} \cdot \text{year}^{-1}]\); \( V \) – volume of material loss in \([\text{mm}^3]\) – exposure time of the test sample in \([\text{number of days}]\); \( \tau \) – exposure time of the test sample in \([\text{hr}]\); \( h_r \) – number of hours of the year \([8760 \text{ to } 8784}]\).

An example of corrosion loss and corrosion rate depending on exposure times at temperature 50°C for test steel EN C22R is in Table 2 and for test steel EN 10131 (see Table 3). An example of the sample surface [2] after the corrosion test is shown in Fig. 5.

### Table 2

<table>
<thead>
<tr>
<th>Exposure time ( t ) [hr]</th>
<th>24</th>
<th>48</th>
<th>120</th>
<th>144</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion loss ( K ) [g·m(^{-2})]</td>
<td>98.3</td>
<td>174</td>
<td>364</td>
<td>473</td>
</tr>
<tr>
<td>Corrosion loss ( U ) [mm]</td>
<td>0.01</td>
<td>0.03</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Corrosion loss [%]</td>
<td>0.65</td>
<td>1.16</td>
<td>2.43</td>
<td>3.15</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [g·m(^{-2} \cdot \text{year}^{-1})]</td>
<td>35846</td>
<td>31681</td>
<td>31612</td>
<td>28730</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [mm·year(^{-1})]</td>
<td>4.57</td>
<td>4.03</td>
<td>3.40</td>
<td>3.70</td>
</tr>
<tr>
<td>Corrosion loss ( K ) [g·m(^{-2})]</td>
<td>51.9</td>
<td>110</td>
<td>241</td>
<td>278</td>
</tr>
<tr>
<td>Corrosion loss ( U ) [mm]</td>
<td>0.001</td>
<td>0.01</td>
<td>0.03</td>
<td>0.036</td>
</tr>
<tr>
<td>Corrosion loss [%]</td>
<td>0.34</td>
<td>0.77</td>
<td>1.61</td>
<td>1.86</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [g·m(^{-2} \cdot \text{year}^{-1})]</td>
<td>18907</td>
<td>20077</td>
<td>17564</td>
<td>16936</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [mm·year(^{-1})]</td>
<td>2.41</td>
<td>2.97</td>
<td>2.61</td>
<td>2.41</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Exposure time ( t ) [hr]</th>
<th>24</th>
<th>48</th>
<th>120</th>
<th>144</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion loss ( K ) [g·m(^{-2})]</td>
<td>113</td>
<td>184</td>
<td>380</td>
<td>481</td>
</tr>
<tr>
<td>Corrosion loss ( U ) [mm]</td>
<td>0.015</td>
<td>0.024</td>
<td>0.048</td>
<td>0.0623</td>
</tr>
<tr>
<td>Corrosion loss [%]</td>
<td>2.40</td>
<td>3.90</td>
<td>8.14</td>
<td>10.40</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [g·m(^{-2} \cdot \text{year}^{-1})]</td>
<td>41245</td>
<td>33059</td>
<td>28043</td>
<td>29522</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [mm·year(^{-1})]</td>
<td>5.26</td>
<td>4.31</td>
<td>3.53</td>
<td>3.81</td>
</tr>
<tr>
<td>Corrosion loss ( K ) [g·m(^{-2})]</td>
<td>60.0</td>
<td>127</td>
<td>287</td>
<td>311</td>
</tr>
<tr>
<td>Corrosion loss ( U ) [mm]</td>
<td>0.008</td>
<td>0.016</td>
<td>0.036</td>
<td>0.040</td>
</tr>
<tr>
<td>Corrosion loss [%]</td>
<td>2.49</td>
<td>3.95</td>
<td>8.22</td>
<td>10.45</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [g·m(^{-2} \cdot \text{year}^{-1})]</td>
<td>21900</td>
<td>23251</td>
<td>20951</td>
<td>18908</td>
</tr>
<tr>
<td>Corrosion rate ( v_k ) [mm·year(^{-1})]</td>
<td>2.79</td>
<td>2.97</td>
<td>2.67</td>
<td>2.41</td>
</tr>
</tbody>
</table>

*Note: In Tables 2 and 3, lines 2 to 6 apply to 50°C and lines 7 to 11 apply to 35°C.*
4. Discussion

The aim of the research was to analyze and process the course of corrosion wear respecting selected internal and external factors [3]. The experiment was carried out on two types of steel, where the percentage increase of corrosion on the surface of tested materials and their weight loss were observed (Figs. 6-8).

---

**Fig. 6 Example of dependence of weight loss $K$ on time and temperature**

**Fig. 7 Example of dependence of weight loss $U$ on time and temperature**
The results obtained at the appropriate time intervals were averaged and used as input data with a time value for building a regression model. The results show a strong correlation between surface corrosion percentage and time. The values are scattered near the regression quadrant function, which is useful for the prediction of the corrosion attack. Significant results were obtained by analyzing the corrosion loss of materials. The test samples were weighed before the test, after the test with corrosive fumes and when the fumes were removed. Linear regression functions were also constructed between exposure time and weight loss. Correlation coefficients take values close to 1, so it can be stated that there is a strong correlation between these parameters. In all cases, these coefficients are positive, so it is a direct dependence. The results give general information about the corrosion degradation of the material under given thermal conditions and the respective corrosive environment [1-3]. It can also be stated that the results contain a methodical procedure for the calculation of the weight loss of materials and corrosion rates with applications in operational practice.

5. Conclusion

Iron alloys are still the most widespread construction material in the field of special mobile equipment. These are cast and ductile steels and materials referred to as cast iron. In the case of knowledge of the mechanisms of corrosion processes, corrosion can be substantially reduced. The basic principles consist in the selection and treatment of the relevant material (heat treatment, alloying, protective coatings, electrochemical protection, etc.), in the treatment of the corrosive environment (inhibitors retarding corrosion processes, barrier systems preventing degrading atmospheric components destimulation of the environment by dehumidification and removal of oxygen from the environment, etc.).

In the paper, the authors present selected methods of corrosion resistance testing of two types of steel EN C22R and EN 10131, which are commonly used in special mobile equipment. The corrosion test in salt fog [9], [10] is evaluated in more detail, where bath temperature and exposure time were the variables. Based on these specific test conditions, it is necessary to state that these are not universal results valid for all types of corrosion attack; with the tested materials it was uniform chemical corrosion. The test showed that with increasing temperature the corrosion loss of the material increased intensively. The results show that further tests are needed with different materials and other changing variables. Then the results can determine the dependence of internal and external factors on the corrosion process more accurately. The goal of further testing is to create data libraries of results that will allow the creation of reliable comparison models designed to predict the degradation process of corrosion.

Acknowledgement

Presented work has been prepared with support of the project MOBAUT (DZRO K-202), University of Defense Brno, Czech Republic
References

Machine Learning in the Exploitation and Diagnosis of Railway Traffic Control Systems

R. Pniewski¹, M. Kornaszewski²

¹University of Technology and Humanities, Małczewskiego 29, 26-600, Radom, Poland, E-mail: r.pniewski@uthrad.pl
²University of Technology and Humanities, Małczewskiego 29, 26-600, Radom, Poland, E-mail: m.kornaszewski@uthrad.pl

Abstract

A characteristic feature of railway automation objects is the possibility of their presence in various operating, reliability and diagnostic states. Many years of experience in the operation of railway traffic control systems (SRK) confirm the dependence of their correct functioning on the reliability of the systems and elements forming the technical structure of the systems. In the case of SRK devices, operational tests are the most effective source of information necessary to determine the numerical values of reliability indicators. These tests allow to obtain full information about the behavior of the system under operating conditions (use and renewal).

They are not only the basis for improving the construction of technical facilities and improving the production process, but also allow obtaining reliable information necessary to control the operation process, including renewal, proper organization of maintenance and repair facilities, or forecasting and determining operating costs. The use of increasingly modern SRK systems on Polish railways based on microprocessor and microcomputer technology results in the need to analyse and evaluate their operation, cooperation and forecasting of operational effects, including the renewal process, resulting from the implementation of these systems. The computer-assisted system for analyzing the reliability and safety of railway automation systems developed at the University of Technology and Humanities in Radom will be particularly useful when assessing SRK systems implemented in microprocessor technology, in accordance with the requirements of international institutions recommended by CENELEC EN 50129, 50128 standards.

An important factor in the increase of railway traffic safety is also the improvement of operational decision making (reliability and maintenance) methods of SRK systems regarding the planning of system servicing and methods of emergency procedures.

The final result of the project was an expert system SADEK (System of Operational Data Analysis in Railway Automation). This system will create a huge knowledge base about the entire operation process of railway automation devices. This causes the need to expand the system and the use of artificial intelligence methods in the automatic diagnosis of operational states. The article presents the assumptions and structure of the system based on the R package.

KEY WORDS: machine learning, railway traffic control system, exploitation

1. Introduction

In 2015, as part of the Applied Research Programme and the agreement with the National Centre for Research and Development, the consortium of the Kazimierz Pułaski University of Technology and Humanities in Radom and Scheid&Bachmann Polska Sp. z o.o. accepted for implementation the project entitled "System for collection of operational data and analysis of reliability and safety of railway automation systems". The project carried out at the university concerned a fundamental problem related to railway safety. The project covered the issue of applied research on the reliability of railway traffic control systems (SRK). The research was aimed at improving the methods of making operational decisions which are an important factor in achieving an increase in railway traffic safety.

The implementation of new generation systems by PKP PLK, rapid technological progress mean that the applicable operating system model and the exploitation strategy used require, in such a situation, to generate a new approach in the sphere of managing the operation process of railway traffic control equipment and systems. This area of management, and in particular of solving decision-making problems related to their service, remains practically outside the circle of broad interests of researchers focused on the creation and implementation of solutions useful in operational practice. This condition is the result of a lack of accurate identification of the management area of the operation of railway traffic control devices, existing decision-making problems, availability of necessary information, sources of their creation and methods of transmission in the system.

Information on the state of technical devices and events occurring in the operation system and the course of individual processes is crucial when making effective operational decisions.

The identification of the process of managing the operation and servicing of railway traffic control systems at PKP PLK, analyzing the structure of the operating system, internal documents regulating the process of operating the devices and the exploitation strategy used allowed to formulate and confirmed the legitimacy of attempting to solve research problems such as:

- developing a method of effective use of diagnostic test results;
developing a method for solving decision problems in the exploitation process by proposing procedures supporting decision making.

Consideration also required a number of new research topics including:
- analysis of processes implemented in the operation system, including the determination of probability distributions, e.g., for times of correct operation;
- modeling of activities and processes implemented in the operation system using methods adequate for these purposes;
- developing a model of the operation process of railway traffic control devices as a sequence of events and actions that change their technical condition.

2. Computer-Aided System for the Operation of Rail Traffic Control Systems

The main goal of the project was to develop assumptions and a system solution that, with certain operational criteria, allows for optimization of activities in the management system and costs associated with the operation of railway traffic control systems, resulting in an improvement in the level of safety in rail traffic. This effect was achieved thanks to the implementation of the direct objective and a number of specific objectives defined at the level of individual tasks implemented in the project. The direct goal of the project was:
- developing assumptions for the system for collecting operational data and analyzing the reliability and safety of railway automation systems;
- verification of the assumptions of developed methods and tools supporting the process of making operational decisions in the field of railway traffic control devices and systems based on collected data as well as developed reliability and operating models of selected railway automation systems. Considering the diagnosed needs of PKP PLK, the implementation of these goals consisted in:
  - collecting acquired operational data and their analysis using IT tools developed in the project;
  - verification of accepted assemblies and solutions for the implementation of decision support in the management of the operation of railway traffic control systems in the area of making decisions regarding the physical implementation of selected processes and activities, in particular the rational use of railway traffic control devices, maintenance and recovery of the condition (service process), materials, spare parts, diagnosis condition of devices and testing the nature of destructive processes taking place, modernization of devices, replacement or possible liquidation;
  - preparation and development of implementation assumptions for the introduction of PKP PLK infrastructure manager, Operational Data Analysis System in Railway Automation (SADEK – polish: System Analizy Danych Eksploatacyjnych w automatyce Kolejowej) as a uniform software platform for maintenance needs including the status of railway traffic control devices and subsystems from sections or nodes of the railway network.

Research works, assumptions and design solutions concerned railway traffic control systems operated as part of PKP PLK railway infrastructure, i.e.:
- traffic safety at rail-road crossings;
- station equipment;
- line locks;
- rail-vehicle interaction devices;
- systems for remote control of basic layer devices on a line section.

The concept of project implementation and its scope have been included in the logical sequence of subsequent tasks, in which, according to the adopted research methodology, the main problems of the project were solved in stages.

2.1. Construction of a New Research Laboratory

The goal was achieved by installing Scheidt & Bachmann SRK devices and their integration with SRK devices and systems in operated laboratories of the Faculty of Transport and Electrical Engineering (Fig. 1) [5, 14].

2.2. Design of the System for Automatic Collection of Data on the Status of Devices

The set goal was achieved by developing prototypes of devices that secure data conversion between standards in Ethernet, CAN and RS485 networks, including the specification of the computer network structure and data encryption methods for secure transmission in these networks [2, 13, 15, 16].

The implementation of task No. 2 required carrying out activities whose scope covered:
I. Construction of a fiber-optic network in the building of the Faculty of Transport and Electrical Engineering, securing the conditions for full integration of the laboratories used in the project and connection to the MAN network and testing of connections as part of prototypes and transmission protocols implemented in the task.
II. Development of a prototype design of devices for collecting data from digital interfaces and sending telegrams in the ETHERNET network. Methods to ensure safety in the diagnosed railway automation subsystems.
III. Analysis of secure transmission (encryption) protocols in open systems.

2.3. Development of the Concept of the Operating System of Rail Traffic Control Systems

The goal of the task was accomplished by determining, on the basis of the analysis of the structure of
individual railway traffic control systems, the requirements and specifications of the structure of the support system for
the operation of railway traffic control devices together with the development of requirements for hardware and
software necessary for the implementation of the project [7, 8].

The safety and reliability parameters of individual railway traffic control systems have been determined [9, 10].
The main purpose of the task was to determine the requirements for (created at WTiE) a system supporting the
operation of railway automation devices implemented in the following steps:

I. Analysis of the structure of railway traffic control systems in terms of determining the requirements for
determining the complexity of systems (number of devices in the railway network) and the structure and scope of
recorded operational data.

II. Performing works on the specification of the structure of the system supporting the operation of railway
automation devices.

III. Development of requirements for the complexity of the operating system of railway automation devices.
The assumptions for the functional structure for the SADEK system are presented in Fig. 2.

Fig. 1 Test stands located in WTEI laboratories: a – a general approach to the Laboratory of Elements and Equipment
of railway traffic control systems; b – SKZR type vacancy control system; c – control desk of the ZSB 2000
control system; d – SHL 12 automatic line block

Fig. 2 Functional structure of the SADEK system
Data on the status of railway traffic control devices can be entered into the event database in three ways:

- XLS import - a mail and client server has been implemented in the system to automatically import files and convert to a database format;
- Internet - electronic book E 1758 with all its functions;
- Automatically - from real devices through diagnostic interfaces.

Information from the event database is periodically downloaded by the supervising program and after initial verification and processing sent to the statistical database. The information in the statistical database is processed using the R Package. Information on statistical distributions is prepared and placed in the appropriate fields of the database. The implemented expert system, based on both primary data and statistics, predicts the future state of devices. Operational services may obtain remote access to statistics and conclusions from the expert system.

2.4. Development of the Overall Structure of the Reliability Model with the Possibility of Specifying Individual Rail Traffic Control Systems

The task was implemented through the specifications [3, 6]:

- reliability models for passage automation systems, station devices, line block devices;
- operational models of railway automation systems, including repairable and non-repairable components, in particular the specifications of the repair and repairability of repair systems as well as the specifications of the set of operational states and the scope of reliability tests in relation to the railway traffic control system [17].

Also:

- set of reliability parameters was specified in research on renewable elements with a limited time of repair useful for railway automation systems;
- a method has been developed to assess the correct functioning of rail traffic control systems, including operational and reliability parameters for the needs of the mathematical reliability model.

The implementation of this part of the task included the performance of the following analyzes:

- functional analysis of real railway traffic control devices covered by the area of impact of the Local Control Center,
- specification of the functions of the Local Control Center in running train traffic,
- technical characteristics of train traffic management and control systems,
- analysis of equipment with railway traffic control systems and railway traffic management at the selected existing Local Control Center,
- analysis of the reliability structures of railway automation systems,
- analysis of the reliability structures of technical systems with the possibility of adaptation for railway automation systems.

Based on the above specifications, simulation models of rail traffic control systems have been developed for reliability tests.

2.5. Description of Technical, Operational and Economic Characteristics

The task was achieved by determining the current technical condition of the examined railway traffic control systems based on a set of characteristic features. It was assumed that most types of device damage generate certain associated features (corresponding to certain measurable physical quantities), on the basis of which it is possible to determine the type of damage or its absence. The condition of each device can be described by an excessive number of features, some of which may not reflect the actual state, so it is necessary to select a representative number of features and determine their course and scope. The method based on the reliability simulation model developed in stage IV for individual SRK devices was used to extract representative features. In addition, a method for extracting features based on data from real railway traffic control devices found on the railway route was also presented. It uses genetic algorithms and a statistical classifier, specifically its implementation in the form of the SVM (Support Vector Machine) classifier. The review and analysis covered and allowed to determine this range of characteristics - technical characteristics of railway traffic control devices, which is associated with the division into types, types, components (sub-assemblies) taking into account load characteristics, technological and implemented functions. They also included information on technical parameters, operating principles, requirements for use, operation and disposal, documentation and instructions. The technical condition of railway traffic control devices has been described as a set of values of appropriately selected features. Due to the significant number of individual features and the values they can assume, those that were used to assess the technical condition in the operation process were those which, as state features, properly and at the desired level describe the correct operation and cooperation of individual elements and subsystems, as well as the performance of functional functions of the device SRK as a whole. The scope and course of individual features was determined. The classification of environmental factors affecting the elements of devices was made and the types of impacts indicated.

Determination of operational characteristics, as a set of parameters determining the state or behavior of SRK system devices during operation, was performed for the purposes of specification of parameters characterizing the operational model of SRK system devices. The operation process was determined and presented as a joint process of
simultaneous changes in technical conditions and operating states. A set of causally related events between its operational phases and operational states as well as events occurring inside any state and physico-chemical events occurring in the device itself were presented. The modeling area for the operation process of railway traffic control devices was determined. This area includes the analysis of information used to assess the technical condition of equipment, generation of decision problems in the operating system as well as transformation of information and development of necessary operational decisions. A set of operational information for effective resolution of decision problems was determined, as well as criteria for assessing decisions made.

3. Machine Learning in the R Package

Large sets of operational data obtained during the implementation of the project did not allow for full analysis of the data. To increase the effectiveness of the analysis algorithms in the R package, it was decided to use elements of artificial intelligence, in particular machine learning [1]. Machine learning is an abstract description of the problem we want to solve. The solution of the task is possible through the use of a learning algorithm, which on the basis of the training set creates a representation of the solution in the form of a model [11, 12]. Models are divided due to their construction into:

- **geometric model** - instances represented by a set of attributes are placed in Euclidean space. Algorithms creating geometric models are: linear regression, logistic regression, support vector machine (SVM, SMO),
- **logical model** - the model is based on inference based on created rules. The conditional part contains instance attributes with specific values set. In the decision-making part, e.g. for a classification task, we have a class that we assign to the currently examined instance. The algorithms that create logic models are: ID3 decision tree algorithm (implementation J48), JRipper, PART,
- **probabilistic model** - uses probability to model relationships between instances, attributes and classes. The key concept in the model is conditional probability and the Bayes rule built on it. Bayesian provides the theoretical basis for so-called Bayesian networks commonly used in learning algorithms.
- **hybrid model** - these models combine any of the techniques for creating and representing models.

Classification is most often the use of machine learning. It involves assigning a class to each of the new instances (objects). We distinguish between binary classification, where we have two classes to choose from, and a multi-class classification. An example of a binary classification can be determining the occurrence of some damage in a device. The process consists in assigning to the operating data the class ‘damaged’ or ‘functional’. Application of multi-class classification can be recognition of the state of complex objects where the instance is described by attributes (e.g. technical states of individual subsystems). The class is the operational condition of the rail traffic control system. Solving the classification task enables a number of learning techniques and algorithms. Such algorithms are called classifiers. Classifiers based on: decision trees (J48, LMT, M5P, DecisionStump) are distinguished, linear regression, logistic regression, supporting vector machine (SVM, SMO), rule generation (JRipper, M5Rules, OneR, PART) and combined methods (AdaBoostM1, Bagging, LogitBoost, MultiBoostAB, Stacking, CostSensitiveClassifier).

Clustering or grouping is another machine learning task. It involves assigning similar instances to the same class. The data for the classification task come from unlabelled learning collections, where there are no explicit classes for instances. Learning algorithms that perform clustering are called clusters. In the RWeka package we distinguish the following clusters: Cobweb, DBScan, FarthestFirst, SimpleKMeans and XMeans. The most popular clustering algorithm is SimpleKMeans, which we will then describe.

R is both the name of the programming language, the name of the programming platform equipped with the language interpreter and the name of the project under which both the language and the environment are developed. R is often called a statistical package. This is because of the huge number of statistical functions available. R is a GNU project based on the GNU GPL license. This means that it is completely free for both educational and business applications. The R language is an interpreted language, not a compiled language. Using R boils down to specifying a sequence of commands to be executed. More commands they can be entered line by line from the keyboard or they can be executed as a script (i.e. a text file with a list of commands to be saved).

Scripts can be executed independently of the hardware platform, which enables data analysis in distributed systems, which include SADIEK. The R program allows you to create and distribute packages that contain new features. Currently over 10,000 packages are available for a variety of applications, e.g. rgl - for three-dimensional graphics, lima - for analyzing microarray data, seqinr - for analyzing data genomic, psy - with statistical functions commonly used in psychometry, geor - with geostatistical functions, Sweave – to generating reports in LATEX and many, many others. The R package allows you to perform functions from libraries written in other languages (C, C ++, Fortran), and it is also possible to functions available in the R program from other languages (Java, C, C ++, Statistica, SAS and many other packages). Thanks to this, we can, for example, make a significant part of the program should be written in Java, and R should be used as an external library of statistical functions.

Due to the earlier application of the package for the analysis of operational data of rail traffic control systems, it was decided to use the machine learning functions contained in the package. Thanks to the network operation and the ability to run scripts on any platform, the necessity to intervene in the operating system for collecting and analyzing operating data has been avoided. An additional computer connected to the system was used to test the machine learning algorithms.
4. Conclusions

The use of machine learning elements allows for a more precise analysis of the operational states of rail traffic control systems. Thanks to such a solution and analysis of a large amount of data, the possibility of predicting device states was obtained [4]. Earlier prediction of operating conditions allows replacement of system components before critical damages occur, which may affect the safety of operated systems. In the prototype version of the operational data analysis system, simple learning algorithms were used to verify the proposed solution.

The results obtained allow a positive assessment of the method used. In the course of further research, extensive methods of machine learning (deep learning) will be used.

References

The Methodology for Evaluating Constraints in Logistics Chains while Utilising Intermodal Transport

Š. Kudláč¹, J. Majerčák², E. Zmeškal³

¹University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, E-mail: stefan.kudlac@fpedas.uniza.sk
²University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, E-mail: jozef.majercak@fpedas.uniza.sk
³University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, E-mail: ekaterina.blinova@fpedas.uniza.sk

Abstract

The article discusses the methodology for evaluating constraints in logistics chains while utilising intermodal transport. The methodology defines some relevant constraints, the way of determining the weights for individual constraints as well as the way of comparing the levels of constraints in various variants. The proposal may be widely applied in real life for planning and selecting an appropriate variant of the logistics chain thanks to processing in the form of a software tool. The methodology may be used by logistics operators, forwarders, carriers, shippers or other subjects in order to plan logistics chains when specific conditions are determined.

KEY WORDS: logistics chain, evaluation of constraints, intermodal transport

1. Introduction

An effective realisation of logistics chains requires excluding any potential constraints. The article introduces the methodology for evaluating constraints in logistics chains while utilising intermodal transport. The methodology defines some relevant constraints, the way of determining the weights for individual constraints as well as the way of comparing the levels of constraints in various variants. The methodology may be widely applied in real life for planning and selecting an appropriate variant of the logistics chain thanks to processing in the form of a software tool; it facilitates its application in practice. The methodology may be used by logistics operators, forwarders, carriers, shippers or other subjects in order to plan logistics chains when specific conditions are determined. This way the specific requirements of the entities concerned directly define and limit technologies, techniques, processes and procedures which may be utilised during the realisation of the logistics chains. Based on the set conditions the methodology enables to choose an appropriate variant of the chain with emphasis put on the given conditions [1-7].

2. Logistics Chain

The term logistics chain indicates such a dynamic interconnection of a consumer market with a market of raw materials, materials and parts in its tangible and intangible aspect which purposively comes out from the demand of an end user or which is linked to a particular contract, product, type or group of products [5]. According to the Theory of Constraints there is at least one constraint (a bottleneck) in each process. And the fastest way to improve this process is to focus on the given bottleneck and its subsequent removal. The bottleneck may be represented with each source whose capacity is equal to or less than the requirement put on the source [4].

As part of logistics chains analyses it is necessary to evaluate the overall effectiveness of a chain. Thus we must take into account the following: a limiting factor may be a low as well as a too high capacity of an element with regard to the other elements. This implies that there is a logistics point of the process evaluation it is required to assess the constraints in a material, financial and information flow at the same time. The optimum condition arises when the supply equals the demand, i.e. when the following relation is true: $S = D$, where $S$ - supply, $D$ - demand. In case $S < D$, there exists a bottleneck. If it be to the contrary, i.e. when $S > D$, there exists an inefficiency which is manifested as a bottleneck in another point of the section.

3. Methodology

The sequence of steps of a complex evaluation of constraints in logistics chains while utilising intermodal transport is presented in the flow diagram in Fig. 1.

Before the suggested methodology can be applied it is necessary to assess the possibility of a logistics chain realisation, to set and assess maximums and minimums of a basic criteria level. There are the following criteria:

- possibility of realising the transport from the point of view of properties of transported goods and infrastructure capacity;
- ability to handle the intermodal transport unit ("ITU") in all points of a transport system change;
- minimum capacity of ITU;
- maximum total time of transport;
- maximum level of total costs.

If a variant of a logistics chain does not meet requirements mentioned above, or if it does not amount to a required minimum or maximum level of any of the basic criteria, it will be excluded from further evaluation. Thus a complex evaluation of the appropriateness of the logistics chain is conducted only in case of actually realisable variants.

Since the complex of constraining criteria is too diverse for the purposes of a multicriteria evaluation of constraints in logistics chains, it is required to adapt the evaluations of individual criteria levels, too. It means the level
of some criteria will be evaluated verbally, and the level of others numerically. For the sake of comparison all data will be entered into a decision table, separately for each variant.

In next step it is necessary to set a wider set of potential constraints. Scientific methods, namely FMEA (Failure Mode and Effects Analysis) method will be applied. For the purposes of a multicriteria evaluation the set of constraining criteria was determined on the basis of individual consultations with experts from the area of intermodal transport. The significance of individual constraints and availability of information regarding their level were taken into account.

In order to effectively utilise the multicriteria evaluation in practice some constraints were grouped under a common name, and others, based on their low relevance, were completely skipped from the narrower set. For the purposes of the multicriteria evaluation the final set of constraining criteria is introduced in Table 1.

<table>
<thead>
<tr>
<th>Level I</th>
<th>Level II</th>
<th>Level III</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flows</strong></td>
<td><strong>Categories of flows</strong></td>
<td><strong>Constraining criteria</strong></td>
</tr>
</tbody>
</table>
| Flow of materials | Continuity of a flow of materials | 1. Total time of transport  
2. Conditions of customs procedures |
| | Appropriateness of ITU | 1. Structure and capacity of ITU  
2. Technological options of ITU utilisation |
| | Safety of a flow of materials | 1. Accident frequency  
2. Political situation |
| Financial flow | Level and conditions of a financial flow | 1. Total costs  
2. Payment terms  
3. Financial losses securing  
4. Credibility and solvency of operators |
| Logistics chain | Safety of a financial flow | 1. Safety of financial transactions  
2. Illegal charges |
| Information flow | Level of an information flow | 1. Information on exact delivery time  
2. Technologies for information on a process state  
3. Rate of information on changes  
4. Communication with operators |
| | Safety of an information flow | 1. Internal safety of information  
2. Information technologies for information safety |

**Calculation and Description of a Constraining Criteria Level**

I.I.a. **Total time of transport** – the criterion level is evaluated numerically. The calculation of the criterion level is performed using the following relation: 

\[ C\bar{C}P = \sum_{p=1}^{i} t_p + \sum_{j=0}^{k} t_{js} + \sum_{s=1}^{j} t_s \text{ [day/hours]} \]

where: \( C\bar{C}P \) – total time of transport.
transport, \( t_p \) – time of partial transports (including compulsory breaks and down-times), \( j \) – total number of partial transports, \( t_{lo} \) – time of loading operations, \( k \) – total number of loading operations, \( t_s \) – storing time, \( l \) – total number of storages.

**I.1.b. Conditions of customs procedures** – the criterion level is evaluated verbally and numerically.
- Are contractual relations laid down with INCOTERMS clauses? (a verbal evaluation);
- Are the customs procedures done on the basis of certificates enabling to simplify and accelerate the technological procedure of customs procedures? (a verbal evaluation)
- What is the total number of required customs procedures? (a numerical evaluation)

**I.1.c. Flexibility of operators** – the criterion level is evaluated verbally.
- Is it possible to change the location of the logistics chain termination during its realisation?
- Is it possible to change the route of the logistics chain readily?

**I.1.d. References on reliability of operators** – the criterion level is evaluated verbally.
- Are there any references on reliability of subjects participating in the realisation of the logistics chain with regards to the date of delivery available?

**I.2.a. Structure and capacity of ITU** – the criterion level is evaluated both, verbally and numerically.
- Is the structure of ITU appropriate for the logistics chain realisation from the point of view of loading operations, fixation and shipment protection? (a verbal evaluation)
- What is the utilisation of the ITU capacity in percent? The criterion is evaluated numerically, and the calculation is performed using the following relation: \( V_{fp} = \frac{O_{ITU}}{O_{ZP}} \times 100 \) [%], where: \( V_{fp} \) – utilisation of the loading space, \( O_{ZP} \) – parameters of a shipment (weight or volume, depending on what is crucial), \( O_{ITU} \) – capacity of ITU (depending on parameters of the shipment).

**I.2.b. Technological options of ITU utilisation** – the criterion level is evaluated verbally.
- Is the ITU used appropriate in terms of linking the logistics chain with inter-company technological and logistics operations?

**I.3.a. Accident frequency** – the criterion level is evaluated numerically, and the calculation of the criterion level is performed using the following relations: \( N = \sum_{i=1}^{n} p_i \cdot k_i \), when \( p_i = \frac{l_i}{L} \), where: \( N \) – total level of accident frequency, \( n \) – number of transport systems used, \( p_i \) – a share of the transport system \( i \) in the realisation of the logistics chain, \( l_i \) – distance realised by means of the transport system \( i \), \( L \) – total length of the logistics chain, \( k_i \) – coefficient of accident frequency of the transport system \( i \); values are given in Table 2.

<table>
<thead>
<tr>
<th>Transport system</th>
<th>Coefficient of accident frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air transport</td>
<td>1</td>
</tr>
<tr>
<td>Water/sea transport</td>
<td>2</td>
</tr>
<tr>
<td>Railway transport</td>
<td>3</td>
</tr>
<tr>
<td>Road transport</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2

The criterion may take values from the closed interval \([1, 5]\); the smaller value the criterion takes, the lower the level of accident frequency in the variant of the logistics chain realisation being evaluated is.

**I.3.b. Political situation** – the criterion level is evaluated verbally.
- Does there in any of the countries through which the logistics chain is realised persist the following political situation?
  1. Civil war.
  2. Civil disorders.
  3. A higher risk of terrorist attacks.

**II.1.a. Total costs** – the criterion level is evaluated numerically, and the calculation is performed using the following relation: \( CN = \sum_{i=1}^{k} NP_i + \sum_{j=1}^{m} NM_i + \sum_{i=1}^{m} NS_i + \sum_{i=1}^{n} NC_i + \sum_{i=1}^{n} NIPJ + NO \) where: \( CN \) – total costs, \( NP_i \) – costs on partial transport \( i \), \( k \) – number of partial transports, \( NM_i \) – costs on a handling operation \( i \), \( l \) – number of handling operations, \( NS_i \) – storing costs \( i \), \( m \) – number of storages, \( NC_i \) – customs procedures costs \( i \), \( n \) – number of customs procedures, \( NIPJ \) – costs on rental of ITUs, \( NO \) – other costs not included into previous categories.

**II.1.b. Payment terms** – the criterion level is evaluated numerically.
- What is the shortest payment period for invoices? (number of days)
- What is the level of interest for a late payment?

**II.1.c. Financial losses securing** – the criterion level is evaluated verbally.
- Do the companies participating in the logistics chain realisation have liability insurance in respect of its realisation?

**II.1.d. Credibility and solvency of operators** – the criterion level is evaluated verbally.
- Is there any information on a seamless financial situation of enterprises participating in the logistics chain realisation available?

**II.2.a. Safety of financial transactions** – the criterion level is evaluated verbally.
- Do the financial operations performed use a documentary credit or a documentary collection?

**II.2.b. Illegal charges** – the criterion level is evaluated verbally.
- Does there exist any information on asking for illegal charges with regards to the logistics chain realisation?

**III.1.a. Information on exact delivery time** – the criterion level is evaluated verbally.
- Do the contracting companies participating in the logistics chain realisation mention any information on the exact delivery time of the shipment to its required destination?

**III.1.b. Technologies for information on a process state** – the criterion level is evaluated both, verbally and numerically.
- Do the companies participating in the logistics chain realisation have any technologies enabling to provide the information on the position of ITU in real time available? (a verbal evaluation)
- How often is the information on the position of ITU updated? (a numerical evaluation)

**III.1.c. Rate of information on changes** – the criterion level is evaluated numerically.
- How fast do the companies participating in the logistics chain realisation provide any information on possible unforeseeable situations and changes arisen during this realisation?

**III.1.d. Communication with operators** – the criterion level is evaluated verbally.
- Is the quality of communication with companies participating in the logistics chain realisation smooth?

**III.2.a. Internal safety of information** – the criterion level is evaluated verbally.
- Do the companies participating in the logistics chain realisation have a contractually bound obligation with their employees to keep a trade secret?

**III.2.b. Information technologies for information safety** – the criterion level is evaluated verbally.
- Do the companies participating in the logistics chain realisation keep the information on the trade secret in a closed internal information system, with no possible external unauthorised access to the system?

4. **A Determination of Weights of Constraining Criteria**

The significance of individual criteria is variable depending on particularities of commodities being transported, geographic characteristics, chosen route of the chain, and others. The significance of criteria is to a large extent influenced with individual and specific needs of a subject who the logistics chain is realised for. And since these needs do change over time, in order to reach an effective evaluation it is necessary to introduce a system for determining the weights of individual criteria which enables to consider specific needs of the subject in real time of the evaluation.

The weights of constraining criteria are determined using the Saaty's method through a pair-wise comparison. The difficulty of the process when the weights of individual constraining criteria are determined can be defined with the total number of mutual comparisons. This number is directly proportional to the total number of constraining criteria; its calculation is performed using the following relation: \( PP = \frac{n(n-1)}{2} \), where: \( PP \) – the total number of comparisons, \( n \) – the number of constraining criteria.

With respect to the difficulty of calculations the process of determining the individual criteria weights is divided into three levels in the methodology, as it has already been presented in Table 1:
1. Basic logistics flows;
2. Categories of logistics flows;
3. Specific constraining criteria.

5. **A Software Tool for a Complex Evaluation of Constraints in Logistics Chains**

A software tool developed for an effective utilisation of the evaluation methodology in practice considerably simplifies the method of evaluation thanks to a graphical element which allows for a pair-wise comparison of individual criteria significance as well as a mutual comparison of the level the criterion reaches in different variants of the logistics chain realisation. The software environment is introduced in Fig. 2.

The evaluation of constraints using the software tool is divided into ten sheets of a Microsoft Excel workbook. After working out the decision tables the evaluator will go through all sheets step by step and they will get to the final evaluation of the logistics chain appropriateness. The Sheet No. 1 serves as an aid for the evaluator and it presents the sequence of steps during the evaluation. Sheets No. 2 - 6 serve for setting the weights of basic flows, categories of basic flows and final constraining criteria in the sheets which is user friendly thanks to the graphic elements used. In Sheets
No. 7 - 9 the evaluator compares the levels of constraining criteria in two different variants of realisation. Upon completing the settings and comparisons in Sheet No. 10 the evaluator will see the final evaluation of the expediency of two different variants realisation; this expediency is compared on the overall level as well as on the level of comparing the expediency of realisation from the point of view of basic flows and categories of basic flows.

![Fig. 2 Software Environment of Sheet No. 4](image-url)

<table>
<thead>
<tr>
<th>Flow of materials - constraining criteria of continuity</th>
<th>Index of consistency</th>
<th>Descriptors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constraining criteria</strong></td>
<td><strong>Weight</strong></td>
<td><strong>Crt. 1</strong></td>
</tr>
<tr>
<td>1. Total time of transport</td>
<td>66.24%</td>
<td>6</td>
</tr>
<tr>
<td>2. Conditions of customs procedures</td>
<td>15.87%</td>
<td>5</td>
</tr>
<tr>
<td>3. Flexibility of operators</td>
<td>6.67%</td>
<td>4</td>
</tr>
<tr>
<td>4. References on reliability of operators</td>
<td>16.73%</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow of materials - constraining criteria of ITU appropriateness</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constraining criteria</strong></td>
<td><strong>Weight</strong></td>
<td><strong>Crt. 1</strong></td>
</tr>
<tr>
<td>1. Structure and capacity of ITU</td>
<td>80.00%</td>
<td>1</td>
</tr>
<tr>
<td>2. Technological options of ITU utilisation</td>
<td>20.00%</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow of materials - constraining criteria of security</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constraining Criteria</strong></td>
<td><strong>Weight</strong></td>
<td><strong>Crt. 1</strong></td>
</tr>
<tr>
<td>1. Accident frequency</td>
<td>66.67%</td>
<td>1</td>
</tr>
<tr>
<td>2. Political situation</td>
<td>33.33%</td>
<td>1</td>
</tr>
</tbody>
</table>

![Flow of materials - Constraining criteria of continuity](image-url)

![Flow of materials - Constraining criteria of ITU appropriateness](image-url)

![Flow of materials - Constraining criteria of security](image-url)
6. Conclusion

The methodology introduced above establishes exact procedures for choosing a more appropriate variant of logistics chains realisation in intermodal transport. The methodology is characterised as follows:
- the methodology evaluates constraints in logistics chains in intermodal transport in a complex manner;
- the methodology defines a narrower set of constraining criteria for the evaluation as well as a wider set ensuring a high variability and flexibility of the evaluation;
- the methodology conducts the evaluation of constraints and the choice of the variant of the logistics chain realisation on the basis of specific requirements of the subject in question;
- the methodology allows for a high flexibility and variability of evaluation;
- the methodology is fully applicable in practice.

The methodology for evaluating constraints in logistics chains in intermodal transport defines the determination of weights of constraining criteria as well as the comparison of the level of constraining criteria in different variants of the realisation on the basis of specific needs, requirements and options of the subject who the evaluation in conducted for. Logistics operators building the logistics chain, forwarders, carriers conducting the evaluation of constraints, e.g. for the purpose of selecting an appropriate transport route, and also individual shippers represented by workers responsible for logistics processes of the organisation may act as the subject.

Acknowledgment

The paper was supported by the VEGA Agency, Grant No. 1/0379/20 "Socio-economics aspects of rail transport market services deregulation in the context of EU legal framework and sustainable mobility", at Faculty of Operations and Economics of Transport and Communication, University of Žilina, Slovakia.

References

Reconstruction of Emergency Vehicle Traffic Accident Using On-Board Camera Recording and Point Cloud Obtained by the Agisoft Metashape Program

E. Kolla¹, V. Adamová²

¹University of Žilina, 1. mája 32, Žilina, 010 26, Slovakia, E-mail: kolla@uniza.sk
²University of Žilina, 1. mája 32, Žilina, 010 26, Slovakia, E-mail: veronika.adamova@fbi.uniza.sk

Abstract

A large number of traffic accidents are due to high speed and lack of driver attention. These two accident causes have an even greater impact on the safety risk of emergency vehicle traffic accidents. This is caused by the fact that these vehicles are often moving at a speed higher than the maximum speed that is allowed in a given road section and other drivers have a problem too early react on the moving of emergency vehicle despite the use of audible and visual warning signals. On the other hand, emergency vehicles are often equipped with on-board cameras that record their movement and thus also the eventual crisis. By the reconstruction of emergency vehicle collision, it is possible to analyse the causes of such situations and eventually propose measures to prevent the occurrence of an emergency vehicle traffic accidents. The paper is focused on the introduction of the in-depth reconstruction methodology for emergency vehicle traffic accidents. The method is based on the symbiosis of on-board camera recording and two software tools: PC-Crash and Agisoft Metashape.

KEY WORDS: traffic accident, emergency vehicle, PC-Crash, Agisoft Metashape, accident reconstruction

1. Introduction

According to several studies, emergency medical services (EMS) personnel have a high-risk occupation [1, 2]. The riskiness arises in particular from emergency response driving for rapid transfer to the scene of an emergency and providing service to patients. Although, the professionals of EMS can better identify and respond to the road hazards compared to civilian drivers [3, 4], the results of emergency interventions may be in many cases injury and fatality. Emergency vehicle traffic accidents (EVTAs) are usually fatal collisions with serious consequences, that fell upon persons not only in the ambulance [5]. Most EVTAs and fatalities occurred at intersections and during emergency mode. The frequent rate of intersection related EVTAs confirmed outcomes of the study [6], when almost one half of all researched cases occurred at intersections. Adverse weather and bad driving conditions were more closely associated with accidents at an intersection than on the open road. The highest percentage of researched ambulance accidents were during responding to an ambulance to a call for help (the way towards the patient) or transporting a patient [6, 7]. The most commonly injured persons were the drivers of EMS and drivers of other vehicles. Another result of this research was that more likely to yield an injured victim was during “emergency mode” (red lights flashing and sirens blaring) than when the ambulance vehicle was in “non-emergency mode” (routine driving) [6].

Gustalow highlighted the significant predictors of collisions resulting in injury. There were reviewed predictors like a T-bone mechanism, accidents at an intersection, alcohol or intoxication of the civilian drivers [7].

In another study, the authors focused on the analysis of ordinary traffic accidents vs. EVTAs. Overall results show, that the biggest problem of drivers is visually detecting emergency vehicles approaching in various driving conditions, also that the warning system of emergency vehicles may not be effective in every case. For example, a driver’s vision can be obstructed or limited by buildings, parked vehicles, nighttime, the drivers can be confused in cluttered intersections, urban environments [8].

The comparison of rural and urban EVTAs is represented in the article [9]. It was founded the results indicating that the incidence of urban setting ambulance crashes is greater compared to crashes in the rural setting. On the other hand, the percentage of ambulance crashes with injuries and the severity of consequences on health were more frequent in the rural location. In these cases, the significant independent factors were higher posted speed and lack of restraints in the rural environment. The conditions like night driving, low weather and road conditions, intersections do not have a significant influence on differences between urban and rural crashes. A similar problem is presented in the study [10]. The authors outlined the problem with motorcycles and generally, the urban environment was significantly more frequent than the rural in the annual number. Emergency vehicles had a frontal impact, in the fatal cases and most of all EVTAs occurred in road intersections.

To be able to define the exact technical cause and conditions of accidents, it is necessary to use dedicated procedures and reconstruct the course of the accident. The purpose of this paper is to introduce an innovative method, that presents a deep reconstruction of EVTAs using dashcam recording, point cloud obtained by the Agisoft Metashape program and simulation in the software PC-Crash.
2. Material and Methods

This part of the paper deals with individual steps of work methodology. There are input materials necessary to do deep reconstruction of a traffic accident. The principle of a deep reconstruction lies in the implementation of the following elements.

The first source material is videorecording from the dashcam. Generally, a dashcam is constructed like digital cameras that provide optical digital evidence of the course of the traffic accident or other traffic incidents. Videorecording is a sequential file of photographs with a defined time step between 2 consecutive frames. The frame rate of on-board cameras usually ranges from 25-30 Hz (lower series cameras) to 50-60 Hz (higher series cameras). Based on the known frame rate of videorecording and the known position of the object of interest from videorecording, the analyst of traffic accidents can determine the average speed between these frames. For the right determination of the position of a given accident object in a key frame it is needed correct of videorecording (e.g. removal of radial distortion of videorecording – fisheye distortion, increase contrast, brightness, etc.). The edited videorecording should have rectilinear character.

The second source material is a point cloud obtained by the Agisoft Metashape software [11]. It is a photogrammetric software tool based on the principles of the digital image correlation for retrospective spatial reconstruction. The program uses a large number of frames with a high degree of overlap (identification of common/homological key features between frames), that are automatically processed and then generated from the three-dimensional point clouds or triangular polygon networks. The workflow is divided into four steps. The first step is image alignment. The outcomes of this phase are sparse point cloud, that represents the spatial arrangement of the scene, the position of all frames in the space at the time of shooting (features of external frame orientation) and the model of the photograph used (features of internal orientation). The second step is a spatial reconstruction using “Dense Multi-View Reconstruction algorithm”. The user can specify the scope and resolution of the resulting model. The outcome is a dense point cloud. The third step is making a spatial model - it is the conversion of the obtained dense point cloud into the form of the triangular polygonal network. The last one is the transformation and validation of measurements. Frame position is one of the most important parts of the evidence workflow. It is effective to do the gradual parallel shooting, with constant height and orientation of images, in the case of the documentation of the traffic accident [12].

The reconstruction method of traffic incident was applied using PC-Crash [13]. PC-Crash is a software tool that is used for reconstruction and simulation of traffic accidents. It contains several computational models, including e.g.: a numerical model of the collision by the method of impulses and momentum, stiffness model of collision calculation, a simple kinematic model for the analysis of spatial-temporal connections and the kinetics model for realistic simulation of vehicle movement with the mathematical-physical model of the vehicle. Besides the above mentioned calculation modules also other additional modules are part of the PC-Crash: module of a multi-body system, a module of finite element method, as well as the possibility of import and work with a 3D cloud point [14].

The schematic overview of the workflow in the proposed method can be seen the Fig. 1. As a source data only two inputs are in principle sufficient: videorecording from the dashcam of emergency vehicle (1) and digital photos of the incident scene (2) created according to the correct photogrammetric principles. From the digital photos of the accident scene a dense point cloud (5) in Agisoft Metashape is created using the principles outlined above. From the digital videorecording of the incident the identification of relevant vehicles (4) is made (it is assumed that the type and model of emergency vehicle are known) and after removal of radial distortion (if present in the videofootage) keyframes from the undistorted videorecording are also exported (3). The time step between keyframes should be chosen in such a way that the position of the vehicles in each subsequent keyframe should be at least one vehicle length apart. This is needed because too dense positioning of the vehicles would exacerbate errors due to the manual positioning of the vehicles in the incident scene model. Afterwards, the simulation project in the PC-Crash simulation software (7) is created. The point cloud of the incident scene is imported to the PC-Crash to serve as an accurate model of the incident scene and vehicle models with accurate physical parameters and realistic 3D shape are imported as well. If needed, an accurate profile of the road is created by triangulation of point cloud to get slope polygons.

In the next step keyframes from the undistorted videorecording are imported into the 3D window of PC-Crash (6). The given keyframe is overlayed with the point cloud and corresponding pairs of aligning points are marked. These points should be ideally located evenly within the viewing cone of the dashcam - markings on the road as well as features in 3D space, like vertical traffic signs, poles, tunnel features, etc. When a sufficient number of aligning point pairs is marked then the reconstruction of the camera parameters ($x, y, z$ position; angles of rotation and focal length) is made (8). This reconstruction of camera parameters is made for each keyframe and for each keyframe positions of relevant vehicles are marked. For emergency vehicles (which dashcam was used) the position of this vehicle corresponds to the position of the dashcam. For another vehicle in the dashcam field of view the position of the given vehicle is realized by moving of the vehicle model in 2D view of the PC-Crash within the incident scene model to a achieve visual overlay of the vehicle model with the position of the real vehicle on the given keyframe (9). Steps (6), (8) and (9) are repeated until the positions of vehicles are reconstructed in the incident scene model in PC-Crash for all keyframes.

When all positions of relevant vehicles in all keyframes are reconstructed in PC-Crash, the trajectory of vehicles can be marked (11) and using a kinetic simulation of PC-Crash the movement of vehicles can be simulated. After the simulation is realized the animation of simulation from the 3D view of PC-Crash is exported and overlayed onto
undistorted videorecording of the incident. The animation of the simulation is created with the parameters of the reconstructed dashcam and connected with the emergency vehicle model. The simulation of the incident scene is correct if there is a visual match between undistorted videorecording and simulation animation.

3. Results

The application of the method is explained in the following traffic accident at the intersection crossing (Fig. 2). The ambulance was travelling on the red signal and the car was travelling to the crossing on the green signal from the left side of the ambulance.

The car did not stop before the movement corridor of the ambulance and collided with the left side of the
ambulance. The ambulance was equipped with the dashcam which recorded the collision with the resolution of 1280 × 960 pixels at the recording speed of 15 frames per second. From the videorecording an identification of relevant vehicles was made: the car that collided with the ambulance vehicle (Mercedes Sprinter) was identified as Peugeot 308 SW (2nd generation, pre-facelift), other vehicles that were relevant for the analysis of the traffic accident were identified as Nissan Qashqai, Ford Focus, Fiat Ducato, Peugeot 207, Mercedes Atego, Skoda Octavia and VW Passat B3 (see Fig. 2). As the videorecording was deformed by the radial distortion, in the next step it was undistorted using proDAD Defishr V1 software [16] so the undistorted videorecording would have rectilinear character and could be used in further steps within the PC-Crash 3D window. Afterwards the frames were exported from the undistorted videorecording using Kinovea software [17] - the keyframes were then selected in such a way that a keyframe was every 5th frame of the undistorted videorecording. As the framerate of videorecording was 15 fps then the time step between two subsequent keyframes was 5/15 = 0,3333 s. This time step ensured the appropriate spacing of vehicles during positioning.

The traffic accident scene was documented by a skilled operator using Nikon D7100 digital SLR camera. Together 411 digital photos were made from which a dense point cloud of the traffic accident scene was created in the Agisoft Metshape software on the workstation HP Z620. The created point cloud of the accident scene was then imported into PC-Crash software (Fig. 3, upper right) and the parts of the road where the motion of the vehicles took part was triangulated as a slope polygon to get an accurate representation of road profile.

Fig. 4 Reconstructed positions of vehicles in keyframes in the 2D window of PC-Crash

Fig. 5 Comparison of the undistorted videorecording and simulation animation (running is from left to right and from above down)
After the import of the point cloud, also the import of the mathematical-physical models of all relevant vehicles was realized together with accurate 3D shapes. Then in the 3D window of PC-Crash the keyframes from undistorted videorecording were imported one by one as a background image and through pairs of aligning points common for both given keyframe as well as a point cloud the reconstruction of virtual camera parameters for each keyframe was done using function “Optimize camera position”. When correct parameters for the virtual camera were identified by optimizing the function of PC-Crash a visual match in overlayed keyframe and point cloud was obtained (Fig. 3).

After the virtual camera parameters were reconstructed to be in match with real world dashcam for a given keyframe, the position of models of relevant vehicles at given keyframe in the 3D window of PC-Crash was aligned in such a way as to be an overlay over the position of the real world vehicle. Afterwards, these positions were marked in 2D window of PC-Crash. Reconstruction of the positions of the ambulance dashcam (which marks the position of the ambulance) as well as of the car in keyframes is depicted in Fig. 4. Trajectories of both vehicles are also depicted in Fig. 4.

As a final step a kinetic simulation of movement of relevant vehicles on assumed trajectories was performed iteratively, so that the animation of the simulation was in a visual match with undistorted videorecording - i.e. movement of all relevant simulated vehicles was in a visual match with the movement of real world vehicles. For that purpose, the Kinovea video player was used. The result of the simulation and comparison of the simulation animation and undistorted videorecording in time step 0,4 s is shown in Fig. 5. The 2D view of the simulation results in time step 0,4 s is shown in Fig. 6.

Fig. 6 2D view on the simulation result

4. Conclusions

The presented method offers an accurate reconstruction of traffic incidents of emergency vehicles (traffic accident as well as a near-miss incident) using relatively barebone input sources: videorecording from the emergency vehicle dashcam and 3D point cloud obtained through photogrammetry. As the method uses software that is either already in use by experts in the field of traffic accident reconstruction (PC-Crash, Agisoft Metashape), is open source and free (Kinovea) or is relatively cheap to buy (proDAD Defisher V1) it is relatively low cost approach to the incident reconstruction. At the same time it serves as a much more accurate approach to the analysis of traffic accidents when compared to standard reconstruction methods based on indirect evidence (e.g. evaluation of crash energy [18], or pedestrian body throwing distance [19]). Further, benefit of the method lies in the fact that also accurate synchronization of traffic participants within accident reconstruction is possible, which is for example not possible in the otherwise accurate method of analyzing Event Data Recorder of a given vehicle (i.e. presented in [20]). Last but not least, the method offers also the possibility to reconstruct traffic incidents that did not end in a collision - near-miss incident. The possibility to reconstruct also near-miss incidents offers massively extensive data to further analyze to identify the technical cause of such an incident and then to propose suitable solution proactively even before the traffic accident happens.

Acknowledgements

Publication was created within the ENABLE-S3 project that has received funding from the ECSEL Joint Undertaking under Grant Agreement no. 692455. This Joint Undertaking receives support from the European Union’s HORIZON 2020 research and innovation programme and Austria, Denmark, Germany, Finland, Czech Republic, Italy, Spain, Portugal, Poland, Ireland, Belgium, France, Netherlands, United Kingdom, Slovakia, Norway. This work was also partially supported by Ministry of Education, Science, Research and Sport of the Slovak Republic.

This work was supported by the Slovak Research and Development Agency under the contract no. SK-IL-RD-18-0005.
References


System Approach to Assessing the Criticality of Key Elements in Road Transport

E. Sventeková¹, M. Ballay², P. Prievozník³

¹University of Zilina, Faculty of Security Engineering, Univerzitná 8215/1, 010 26 Zilina, Slovakia, E-mail: eva.sventekova@fbi.uniza.sk
²University of Zilina, Faculty of Security Engineering, Univerzitná 8215/1, 010 26 Zilina, Slovakia, E-mail: michal.ballay@fbi.uniza.sk
³University of Zilina, Faculty of Security Engineering, Univerzitná 8215/1, 010 26 Zilina, Slovakia, E-mail: pavol.prievoznik@fbi.uniza.sk

Abstract

As new technologies evolve, the requirements for transport infrastructure safety are increasing. Transport infrastructure contains a set of key elements in which disruption or destruction would have a significant negative impact on the economic and social functioning of countries. The paper presents a model of a systematic approach to identifying and assessing the criticality of key elements in road transport. The model contains a proposal of a set of relevant criteria, using which it is possible to clearly define a set of all significant (key) elements of road infrastructure. These criteria are formed by using quantitative parameters with threshold values. Based on the proposed thresholds, it is possible to assess the importance of all typological elements of road infrastructure in terms of their impact on the transport system and to evaluate the criticality level of the elements and to decide on their key importance in terms of national, regional or local transport infrastructure.

KEY WORDS: road transport, a key element, assessing the criticality

1. Introduction

Transport is one of the most important factors in the technological development of mankind. During the historical development of civilizations, it has become an everyday prerequisite for the social and economic functioning of society. Along with the advent of new technologies, the requirements for uniform safety of transport infrastructures are constantly increasing. Road transport is currently one of the most widely used modes of transport and there is a number of key elements in its infrastructure, the disruption or destruction of which would have significant negative effects on the economic and social functioning of states.

The densely built road network in the EU makes it possible to draw detours along other functional roads in the event of a disruption of one of the roads. And although there will be no complete disruption of the state economy, transport requirements will be met with some time delay. The malfunction of a key transport element brings with it certain economic losses for companies, in some entire regions or throughout the country. In addition to economic losses, damage or malfunction of elements of critical road infrastructure can also have serious consequences for the health and life of the population. These are mainly buildings with an increased concentration of people, such as bus stations, but also more complex transport structures such as bridges and tunnels, especially during peak hours.

In the conditions of the Slovak Republic, there are currently no systemic approaches to determining the key elements of infrastructure at the regional or local level, which would contain specific criteria for assessing the importance of these elements. After analysing the road network sub-sector, the team of project developers identified typological categories of elements and came to believe that their different typological characteristics will need to be respected when further assessing the elements and drafting relevant criteria for identifying potential elements of the road infrastructure.

In creating the methodology, the researchers used methods of analysis, synthesis, description, comparison, mathematical and simulation methods, decision methods and a specific FMEA method. The paper will present a model and methodology for determining the key elements of road transport with a proposal for quantifiable parameters. Exactly expressed numerical values of the characteristics of road elements and percentage expressions of the degree of fulfilment of criteria will enable unambiguous identification and comparison of any typological elements with each other.

When drafting the criteria and methodology for determining the set of critically important elements of road infrastructure, the valid legal norms in the field of road transport and critical infrastructure in Slovakia were respected. The proposal is based on an analysis of approaches to the identification of critical infrastructure elements in transport according to European and national legal standards, professional literature, scientific publications, projects and research tasks.
2. The Topic of Research

The topic of the research is the identification of all those elements of road infrastructure that have a significant impact on the proper functioning of the transport system. For example, elements that can potentially form a significant part of road infrastructure at the local or regional level can be included in this set. The "criticality" of these elements is determined primarily by the demanding substitutability and impact on the transport system in the event of loss of their functionality. The proposed criteria for the methodology for identifying significant infrastructure elements may apply to regional and local structures. Using the proposed methodology, it will be possible to assess the relative importance of individual objects in relation to regions, cities and municipalities. The proposal is universally applicable. The methodology for determining the elements through the proposed criteria can be used to assess any typological element of the road infrastructure [4].

3. Criteria for Identifying Key Elements of the Road Network

The first step in the process of designing a system for identifying significant road infrastructure elements is to establish a basic set of relevant criteria. To create a comprehensive design of criteria, the model was created divided into several levels (Fig. 1). The basis of the model is a set of main criteria formally designated as C1, C2, C3 and C4 (hereinafter only the main criteria). These criteria are defined as follows: detour route (C1), design properties (C2), the importance of the element (C3) and riskiness of surrounding (C4). Each of the main criteria contains a subset of several sub-criteria. Through these subsets, individual quantifiable parameters of the main criteria can be specified. The methodology contains a total of 21 criteria - 4 main and 17 sub-criteria. Based on the ratio of fulfillment values, it is possible to quantify the final fulfillment rate of the relevant main criterion by synthesizing the sub-criteria.

![Fig. 1 General model of assessing the criticality of key elements in transport [8, 9]](image)

4. Determining the Weight of the Main Criteria

In a comprehensive assessment of the main criteria, their relative importance needs to be taken into account. To
quantify the degree of influence of individual criteria on the assessed element, a decision matrix was used, in which the main criteria C1-C4 were assigned the appropriate weighting coefficients [2].

The most relevant criterion in the proposed set of criteria is the detour route. The highest priority for this criterion is based on the characteristics of the road network. When the road network is disrupted or destroyed, it is usually always possible to set a detour route. Therefore, we perceive this aspect as the most crucial in the question of the relative importance of the criteria. The criterion was assigned a weight of 0.4.

The second most important criterion for assessing importance will be the criterion of the design properties of the element. The basic construction characteristics of road infrastructure elements, such as section length, road width, rate of loss of function and speed of renewal, are determinants of the potential substitutability and financial complexity associated with the renewal of the element. The criterion will be assigned a weight of 0.3.

Another criterion is the importance of the element. Although the importance of the elements is undoubtedly one of the most key factors in assessing the impact on the transport system, it will be given a lower priority in the proposed methodology with a weighting factor of 0.2. The main reason for this decision is the fact that the importance of the elements within the individual territorial areas forms a separate part at the end of the process of criteria assessment of the elements.

The lowest priority is given to the criterion of the riskiness of surrounding with a coefficient of 0.1. By its nature, road infrastructure is not significantly exposed to risk factors of a natural or anthropogenic nature. The high density of the road network allows traffic to be diverted by alternative routes in the event of a potential threat to a particular road section [6].

5. Expression of the Degree of Fulfillment of the Criteria

In the process of quantifying the assessment of the importance of elements on the basis of the proposed main and sub-criteria, the degree of fulfillment of these criteria will be expressed as a percentage. By means of the percentage calculation of the degree of fulfillment of individual criteria, it will be possible to obtain the final calculation of the level of criticality, resp. importance of elements in the transport system [1]. Details of parameters are in Fig. 2.

![Fig. 2 Expression of the degree of fulfillment of the criteria [1, 3]](image-url)
The course of the loss of function is one of the subcriteria of the design properties of the element (C2). This criterion expresses how quickly the element is eliminated. The rate of loss of function can serve as a determining factor in the potential ability to timely avert a complete malfunction of the element, respectively, prediction of function loss. In Fig. 3 graphically shows the individual types of loss of function curves.

The most critical course of the loss of function is the jump convex course of the decrease of the function. The second most critical course is the hyperbolic course, which can be characterized by a sharp decline in the function of the element, which slows down in the end. The linear course of the decrease in function represents the average course in which the endangered element loses its functionality in linear proportion to time. The parabolic course of the decrease in function represents a slight loss of functionality at the beginning of the time period, which becomes more intense in proportion to time. In this case, it is easier to perform a timely response and prevent the road object from being completely discarded. The least critical is the abruptly concave decrease in function, when it is possible to diagnose in advance the potential risk of element failure and take preventive measures to minimize potential losses.

To express the degree of fulfillment of the criterion, 5 categories are created, to which a percentage value is assigned. The individual waveforms sorted according to the degree of criticality are given in the table in Fig. 2. To achieve 100% fulfillment of this criterion, the course of the loss of function of the element must be determined to be stepwise convex. The hyperbolic course will take on the value of meeting the criterion of 75%, linear 50% and parabolic 25%. In the case of a stepwise concave loss, the value of meeting the criterion will be 0%.

The recovery rate profile shares the characteristics with the function loss rate criterion. The main difference between the two criteria will be that the values of the recovery rate waveform will have inverse waveforms.

![Fig. 3 The course of the loss of function of key element](image)

6. Results

An element will be considered a critical element of road infrastructure of national importance if it achieves the stated criteria values of 80% and higher.

Final calculation:

\[
C = 0.4 \times C_1 + 0.3 \times C_2 + 0.2 \times C_3 + 0.1 \times C_4.
\] (1)

When determining the importance of an element from regional significance, this value will be multiplied by a coefficient of 1.5. If 80% of the criteria are met, multiplied by the coefficient, the element will be identified as a significant element of regional infrastructure. When determining the importance of an element in terms of importance within the local infrastructure, the value of the criteria will be multiplied by a factor of 2. In the case of reaching 80% fulfillment of criteria after multiplication by the coefficient, the element will be determined as a significant element of local infrastructure (municipality, city) [5].

7. Conclusion

The complexity of the infrastructure is expressed by its network structure, in which each individual element can be important for the whole system. In fact, it is not possible to protect all components of the system, so it is important to identify the key elements that ensure the functionality of the system. There are several criteria according to which the
individual elements of the road infrastructure can be assigned their key importance. It is necessary to consider the importance of the element for the road network as a whole, the role of a particular road in the context of the whole road infrastructure of a country or region, know the impact of its failure on traffic flow and safety, as well as the possibility of its recovery after an accident. These facts need to be taken into account when selecting key elements. The assessment of the vulnerability of road network elements consists in the assessment of the level of their vulnerability and the ability to restore their function after the occurrence of an accidental adverse event. As part of the research project, the authors created a process model and a methodology for selecting and evaluating key elements of the road network.

Acknowledgments

This work was supported by the research projects VEGA 1/0159/19 Evaluation of the level of resilience of key elements of land transport infrastructure," and V120152019049 "RESILIENCE 2015: Dynamic Resilience Evaluation of Interrelated Critical Infrastructure Subsystems".

References

Determination of the Law of Probability Distribution of Navigation Measurements

I. Vorokhobin¹, O. Haichenia², V. Sikirin³, V. Severin⁴

¹National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: vorokhobini@gmail.com
²National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: haichenia.ov@gmail.com
³National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: sikirin.v@gmail.com
⁴National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: severin.vitaliy@gmail.com

Abstract

The analysis of the possibility of the stochastic description of navigation measurements using normal distribution law and mixed distribution law of the first and second types have been performed. For a description of navigation parameters random errors Poisson generalized distribution has been suggested.

It has been shown that "fat tails" are inherent in this distribution and it can be applied for dependent random errors description system.

The results of the statistic hypothesis testing of a few experimental samples which show the preference for Poisson generalized distribution over normal distribution.

KEY WORDS: navigational safety, errors of navigational measurements, Poisson generalized law, mixed distribution laws, results of in situ observations

1. Introduction

Determination of a ship's position with the help of several isolines is generalized using position line method wherein isoline is replaced by a line of position in the region of the dead-reckoning position of a ship. Provided there are surplus lines of position selection of observed coordinates is carried out in such a way so that their accuracy could be maximum. It is reached by calculation of coordinates by the method of maximum likelihood an algorithm of which is determined by the law of probability distribution of errors of position lines. Until recent times it has been considered that random error of measurements of navigational parameters as well as errors of lines of position follow normal distribution law, thus calculation of observed coordinates is carried out by the least square method which is a method of maximum likelihood for normal law.

However, for the past 30 years, studies of random errors of measurements of navigational parameters have shown that their distribution laws often differ from Gauss law. That is why the loss of accuracy may occur in case of calculation observed coordinates with surplus lines of position using the least square method.

The efficiency of observed coordinates obtained in course of determining the ship's position by surplus lines of position and calculated by least square method describes the loss of their accuracy applying error distribution lines of position following law which differs from Gauss.

In papers [1, 2] statistical data of errors of navigational measurements obtained via in situ observations have been analyzed and it has been shown that errors do not follow normal distribution law. As has been indicated in paper [3], analysis of statistical data has shown that assumption on the distribution of random errors of determining latitude and longitude following Gauss law is incorrect and requires an alternative approach.

Mixed laws of two types which are alternative to normal law have been suggested to describe random errors of navigational measurements in papers [4, 5], and paper [6] suggests Poisson generalized law with the same purpose.

The evaluation of the efficiency of ship's observed coordinates with surplus lines of position has been performed in paper [7], it has been shown that in case if mixed distribution laws efficiency is less than 1, and with increasing of mean parameter it tends to 1.

The objective of the present article is an analysis of the possibility of application of various laws on the distribution of random variables as the law of distribution of errors of parameters of navigational measurements.

2. Presentation

It is common to assume that random errors of measurements of navigational parameters follow normal distribution law the density of which is shown as:
However, as it is shown in paper [8], analysis of statistical data obtained in situ observations under real operational conditions has shown that errors of parameters of navigational measurements follow mixed distribution laws of two types, densities of which are shown as [4, 5]:

\[
f_1(x) = \frac{2^{\frac{3}{2}} \pi^{\frac{1}{2}} n!}{\sqrt{2\pi} \cdot 1 \cdot 3 \cdot (2n-1)} \frac{1}{(x^2 / 2 + \alpha)^{2n+1}}, \quad (n \leq 6);
\]

\[
f_2(x) = \frac{1 \cdot 3 \cdot 5 \cdot (2n+1) \alpha^{2n}}{\sqrt{2} 2^{n+1} \pi n!} \frac{1}{(x^2 / 2 + \alpha)^{2n+1}}, \quad (n \leq 5),
\]

where \(\alpha\) – scale parameter; \(n\) – mean parameter.

Mixed distribution laws of both types are characterized by "fat tails", which correspond to experimental data. However, given laws cannot be applied for dependent errors of measurements as they are not invariable or infinitely divisible.

This disadvantage is not inherent for Poisson generalized law in the model of which there is a condition that accuracy of measurement of the navigational parameter is influenced by a multitude of factors either of each stipulates the appearance of individual error \(\eta_i\), provided that all errors \(\eta_i\) are similarly distributed by independent random values with density \(g(\eta)\), which is called construct.

The peculiarity of the considered model is the assumption that a number of factors which simultaneously influences the accuracy of measurements is a random value, as the probability of the presence of each factor in the complex of conditions of parameter measurement differs from 1, i.e. influence of each factor on the measurement process is random – under specific conditions factor may influence as well as be absent.

If the probability of appearance of each factor is similar, the probability of simultaneous influence of \(k\) factors on the accuracy of measurements follows Poisson law which has an analytical expression:

\[
P(N = k) = e^{-c} \frac{c^k}{k!},
\]

where \(c\) – mean parameter.

In this case error of navigational measurements \(\xi\) is equal to the sum of individual errors \(\eta_i\), \(\xi = \sum_{i=1}^{N} \eta_i\), wherein \(N\) is a random discrete value. Provided that density of distribution \(\xi\) is \(N\) – fold convolution \(g(\eta)\), such convolution is indicated by \(g^N(\eta)\).

Taking into account that a number of factors may vary from 1 to \(\infty\), random value (measurement error) \(\xi\) takes value \(\sum_{i=1}^{k} \eta_i\) with probability \(\exp(c) \frac{c^k}{k!}\), wherein its distribution density \(g^k(\eta)\) and therefore for the range \(k\) density \(f(\xi)\) is determined by Poisson generalized distribution [6]:

\[
f(\xi) = \exp(-c) \sum_{k=0}^{\infty} \frac{c^k}{k!} g^k(\xi).
\]

According to [6], density \(f(\xi)\) is a family of Poisson generalized distributions that is produced by density \(g(\eta)\). The characteristic function \(\varphi(t)\) of density \(f(\xi)\) is determined by the characteristic function of producing density \(g(\eta)\) (it is indicated as \(\varphi(\eta)\)), formula [6]:

\[
\varphi(t) = \exp\{-c[\varphi(\eta) - 1]\}.
\]

The main and very important advantage of Poisson generalized distributions is their infinite divisibility. Provided that density \(f(\xi)\) can be resolved into components with different variances, which are considered to be a crucial circumstance for dependent measurements. So that the density of distribution \(f(\xi)\) could be used for the description of navigational measurement, density \(g(\eta)\) must have \(k\)-fold convolution with itself in an explicit form. Moreover, for peakedness with which "fat tails" take place, the next inequality must be observed:
\[
\frac{\psi^{IV}(0)}{3[\psi^II(0)]^2} = 1 + \frac{c \frac{\partial^4}{\partial t^4} \psi(0)}{3c^3 \left[ \frac{\partial^3}{\partial t^3} \psi(0) \right]^2} > 1,
\]

where \(\psi^II(t)\) and \(\psi^{IV}(t)\) – the second and the fourth derivatives of the characteristic function \(\psi(t)\).

This condition is observed with \(c < \infty\), therefore, with any symmetrical density \(g(\eta)\). Poisson generalized distribution \(f(\xi)\) will satisfy the inequality mentioned above.

Let us consider Poisson generalized distribution which is produced by Gauss distribution. Expressions for generating density and its convolution is given by:

\[
g(\eta) = \frac{1}{\sqrt{2\pi}\sigma} \exp \left( -\frac{\eta^2}{2\sigma^2} \right);
\]

\[
g^{*}(\eta) = \frac{1}{\sqrt{2\pi k\sigma}} \exp \left( -\frac{\eta^2}{2k\sigma^2} \right).
\]

Therefore, Poisson generalized distribution with Gauss generating density is expressed as follows:

\[
f_G(\xi) = \exp(-c) \sum_{k=0}^{\infty} \frac{c^k}{k!} \frac{1}{\sqrt{2\pi k\sigma}} \exp \left( -\frac{\xi^2}{2k\sigma^2} \right).
\]

Or after transformation:

\[
f_G(\xi) = \frac{1}{\sqrt{2\pi\sigma}} \exp(-c) \sum_{k=0}^{\infty} \frac{c^k}{k!} k^{-\frac{1}{2}} \exp \left( -\frac{\xi^2}{2k\sigma^2} \right).
\]

Density \(f(\xi)\) complies with characteristic function \(\psi_G(t)\):

\[
\psi_G(t) = \exp \left[ -c \left( e^{\frac{t^2\sigma^2}{2}} - 1 \right) \right].
\]

In the course of a voyage in situ observations in which 8 samples of errors of measurements of navigational parameters have been obtained have the characteristics which are presented in Table 1.

<table>
<thead>
<tr>
<th>Sample №</th>
<th>Navigational parameter</th>
<th>Number of measurements</th>
<th>Mean value</th>
<th>Variance</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bearing</td>
<td>210</td>
<td>217.41°</td>
<td>0.222</td>
<td>0.47° = 28.3'</td>
</tr>
<tr>
<td>2</td>
<td>Distance</td>
<td>210</td>
<td>0.3378 mm</td>
<td>19.7</td>
<td>4.44 m</td>
</tr>
<tr>
<td>3</td>
<td>Latitude</td>
<td>210</td>
<td>28°49'.1005 S</td>
<td>47.13</td>
<td>6.87 m</td>
</tr>
<tr>
<td>4</td>
<td>Longitude</td>
<td>210</td>
<td>32°02'.8950 E</td>
<td>44.4</td>
<td>6.67 m</td>
</tr>
<tr>
<td>5</td>
<td>Bearing</td>
<td>250</td>
<td>122.21°</td>
<td>0.246</td>
<td>0.49° = 29.76'</td>
</tr>
<tr>
<td>6</td>
<td>Distance</td>
<td>250</td>
<td>0.1206 mm</td>
<td>5.68</td>
<td>2.38 m</td>
</tr>
<tr>
<td>7</td>
<td>Latitude</td>
<td>250</td>
<td>14°41'.0030 N</td>
<td>38.11</td>
<td>6.17 m</td>
</tr>
<tr>
<td>8</td>
<td>Longitude</td>
<td>250</td>
<td>17°25'.4313 W</td>
<td>39.84</td>
<td>6.31 m</td>
</tr>
</tbody>
</table>

For each sample a histogram has been produced and the checking of statistical hypothesis has been carried out in course of which the degree criterion of statistical sample data with selected laws of distribution of probabilities of errors has been determined. The next laws have been selected as an alternative: normal law, mixed laws of the 1st and 2nd types and Poisson generalized law, analytical density expressions of which are presented in Table 2.

Table 3 presents values of mean parameters of distribution laws with which minimum values of \(\chi^2\) – Pearson criterion are reached for each of the laws.
Table 2

<table>
<thead>
<tr>
<th>Distributions</th>
<th>Analytical expressions of density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauss</td>
<td>( f(x) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{x^2}{2\sigma^2}\right) )</td>
</tr>
<tr>
<td>Mixed law of the 1st type</td>
<td>( f_1(x) = \frac{2^n (2+\alpha)^{n/2} n!}{\sqrt{2\pi} \cdot 1 \cdot 3 \cdot (2n-1)} \frac{1}{(x^2 - 2\alpha)^{n/2}}, \ (n \leq 6) )</td>
</tr>
<tr>
<td>Mixed law of the 2nd type</td>
<td>( f_2(x) = \frac{1 \cdot 3 \cdot 5 \cdot (2n+1)\alpha^{n+1}}{\sqrt{2\pi} \cdot n!} \frac{1}{(x^2 - 2\alpha)^{n+1/2}}, \ (n \leq 5) )</td>
</tr>
<tr>
<td>Poisson generalized law</td>
<td>( f_0(\xi) = \frac{1}{\sqrt{2\pi\sigma}} \exp(-\xi) \sum_{k=1}^{\infty} \frac{\xi^k}{k!} \exp\left(-\frac{\xi^2}{2\sigma^2}\right) )</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Gauss ( \chi^2 )</th>
<th>1st type ( \chi^2 )</th>
<th>2nd type ( \chi^2 )</th>
<th>Poisson ( \chi^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 / 2</td>
<td>7.660 / 8.749</td>
<td>0.0126 ( n = 2 ) / 0.0124 ( n = 3 )</td>
<td>0.0144 ( n = 2 ) / 0.0120 ( n = 2 )</td>
<td>0.0255 ( \gamma = 3.75 ) / 0.0167 ( c = 3.75 )</td>
</tr>
<tr>
<td>3 / 4</td>
<td>7.168 / 9.118</td>
<td>0.0106 ( n = 6 ) / 0.0140 ( n = 1 )</td>
<td>0.0108 ( n = 5 ) / 0.0340 ( n = 1 )</td>
<td>0.0100 ( c = 8.00 ) / 0.1090 ( c = 3.75 )</td>
</tr>
<tr>
<td>5 / 6</td>
<td>8.160 / 7.237</td>
<td>0.0097 ( n = 4 ) / 0.0097 ( n = 4 )</td>
<td>0.0095 ( n = 3 ) / 0.0095 ( n = 3 )</td>
<td>0.0103 ( c = 4.00 ) / 0.0103 ( c = 4.25 )</td>
</tr>
<tr>
<td>7 / 8</td>
<td>10.14 / 8.115</td>
<td>0.0110 ( n = 1 ) / 0.0147 ( n = 2 )</td>
<td>0.0320 ( n = 1 ) / 0.0103 ( n = 1 )</td>
<td>0.1067 ( c = 4.00 ) / 0.0393 ( c = 4.00 )</td>
</tr>
</tbody>
</table>

Analysis of Table 3 shows that errors of any samples do not follow normal distribution law, however, they can be described both by mixed law and Poisson's generalized law with a high degree of probability. Under any other equal conditions application of Poisson generalized law is preferable as in case of dependent errors of position lines with Poisson generalized law the system of dependent errors may be changed into an appropriate system of independent errors. In the case of mixed laws of distribution of error measurements such change is impossible as mixed laws unlike Poisson generalized law are not stable.

3. Conclusions

Analytical expressions of the density of mixed laws of both types of distribution of navigational measurement errors which are alternative to Gauss law have been given. An expression of Poisson's generalized law with Gauss producing density has been obtained and its advantage in an application for errors of measurement of navigational parameters has been shown. Results of in situ observations of errors of navigational parameters measurements proving reasonability of application of mixed laws of both types and Poisson generalized law with Gauss producing density have been presented.

References

Land Transport Vulnerability to Power Failure

M. Lusková

University of Žilina, Univerzitna 8215/1, 010 26 Žilina, Slovakia, E-mail: Maria.Luskova@fbi.uniza.sk

Abstract

Transport infrastructure, public passenger transport and other transport services are an integral part of the daily lives of the population. The transport sector together with energy are listed in the Council Directive 2008/114 / EC on the identification and designation of European Critical Infrastructures and the assessment of the need to improve their protection as the European Critical Infrastructure (ECI) sectors addressed by that Directive. ECI is a critical infrastructure located in EU Member States, the disruption or destruction of which would have serious consequences in at least two Member States. Technical and technological advances have continued to increase the standard of living of the population, but on the other hand, the complexity and interdependence of critical infrastructures has been increasing at both national and international levels. Regarding the interconnection of transport and energy sectors, rail transport e.g. provides fuel and spare parts of machinery for power plants supply while electricity in transport provides e. g. operation of signalling equipment, electrified lines, control centres, etc.

The paper deals with the interconnection of transport and energy CI sectors and impacts on transport infrastructure due to the interruption of electricity supply. It presents real events that have led to a paralyzing of transport due to a massive power outage and also points to an increase in the society dependence on electricity due to electromobility. The aim of the paper is to identify transport vulnerability indicators against power outages which can quantify the vulnerability of transport infrastructure and thus improve preparedness for emergencies that are often very dangerous and unpredictable.

KEY WORDS: critical infrastructure, transport, electricity, vulnerability

1. Introduction

Today's modern societies are increasingly vulnerable. On the one hand, technical and technological progress brings society a high level of prosperity and a more comfortable way of life, on the other hand, their dependence on the smooth functioning of various types of social and technical infrastructure increases.

Infrastructure, the destruction or malfunction of which for any reason will cause a serious threat or disruption to the political and economic functioning of the state or a threat to the life and health of the population, is called critical infrastructure (CI). In the Slovak Republic, critical infrastructure is part of the state security system and its protection is one of the priorities for ensuring the security of the Slovak Republic. The approach of individual EU countries to the identification of their own CI sectors is not uniform, but the transport and energy sectors are included in the CI in each country. Both sectors are of European importance, and therefore Council Directive 2008/114/EC on the identification and designation of European Critical Infrastructure and the assessment of the need to improve their protection has focused on these two sectors as European Critical Infrastructure Sectors [1].

2. Transport and Energy Infrastructure Significance

Transport infrastructure and services provided in transport provide a comprehensive service of the territory of the state and the functioning of the economy in the country. They significantly affect socio-economic development, the growth of living standards and increase the country's competitiveness. They contribute to reducing unemployment, are a key factor in the inflow of foreign investment, the development of tourism and help reduce disparities between regions and countries [2, 3].

One of the strategic goals of the transport strategy of the Slovak Republic is to increase the safety and security of transport leading to the permanent provision of safe and secure mobility through a safe infrastructure, introduction of new technologies/procedures using preventive and control mechanisms [4].

The most important transport systems in the Slovak Republic are the rail and road transport system. The current state of road infrastructure is characterized by a relatively dense network of roads, but with a low share of motorways and expressways, especially on major international road connections, the existing capacity of roads is exceeded. In 2018, the transport network of the Slovak Republic consisted of 18,045 km of roads and motorways, of which 482 km were motorways. The length of railway lines was 3,626 km, of which 1,587 km were electrified [5]. One of the basic problems of the transport sector in Slovakia is the long-term unfavorable development of the division of transport work in favor of road transport, especially individual (non-public) transport, while the surrounding European countries with similar economic development also face a similar problem. While in 1995 the ratio of public and non-public transport performance was almost the same, in 2014 public transport accounted for only a quarter of total transport performance. The consequence of this situation is a disproportionate increase in individual car traffic, which represents a burden on
road infrastructure as well as the environment. Also a significant negative effect on roads loaded above the permissible limit is the time loss resulting from congestion, which has an indirect impact on the economic activity of the population [4].

The energy sector is of particular strategic importance as it forms the basis for the safe and reliable operation of any infrastructure, all economic sectors and the provision of the needs of the population. Electricity has a dominant and irreplaceable position in this sector, which represents a daily need for all citizens and the economic life of each country. Electricity is also consumed in the transport of people and goods.

Ensuring security of electricity supply in the Slovak Republic is at a high level. In all stages of preparation of operation, suitable solutions for the operation of the Electricity System of the Slovak Republic are proposed and the necessary space is created for maintenance, innovation and construction of power equipment to ensure long-term reliable, safe, secure and efficient operation of the system under economic conditions. In order to deal with or prevent emergencies, the transmission system operator shall have in place a defence plan to prevent major failures, measures in the event of accidental frequency and voltage changes, as well as a plan of recovery of the system after a black-out failure. Operational safety and security meets the requirements for electricity transmission and is checked at every stage of operational preparation, namely annual, monthly, weekly and daily. The release of transmission system equipment from operation shall be carried out in coordination with neighbouring transmission system operators within all stages of the preparation of operation. The basic evaluation criterion monitored at all stages of preparation for operation is the safety criterion N-1 [6].

The Ministry of Economy of the Slovak Republic in cooperation with the Slovak transmission system operator SEPS, a.s. annually prepares a Report on the results of monitoring the security of electricity supply and on the measures taken and envisaged to address the security of electricity supply. According to the latest report, a growing trend of electricity consumption is being considered in the coming years, taking into account the size of own consumption for the expected development of the production base.

3. Dependence of Transport Infrastructure on Electricity

In terms of CI, transport and energy are among the most important sectors. Regarding the consumption of electricity in transport, the greatest demands on electricity are in the construction of transport infrastructure in the operation of equipment and machinery. Other demands arise from the operation of railway and bus stations, central control stations of major carriers in road and rail transport, central control stations of administration and maintenance of motorways, roads, railway transport routes and tunnels. Energy demands will be constantly increasing due to the operation of lighting, traffic lights, security devices, or heating of buildings. Demands for energy in the form of electricity and fuel arise in transport during the operation of vehicles. Also, the implementation of the Transport development strategy of the Slovak Republic until 2030 may lead to an increase in energy demands due to an increase in traffic volume, or to an increase in electricity demands contrary to the diesel and petrol consumption when shifting part of traffic from roads to railways and when electrifying railways.

The use of transport services within the energy sector provides e.g. rail transport, which provides supplies of fuel and spare parts for machinery in the power plants. An unexpected power outage in transport often causes its collapse as well as chaos among people, mainly due to the malfunction of traffic signalling devices (traffic lights, railway crossing signals, etc.), the cessation of public transport, which is directly dependent on electricity supplies (trains, trams, trolleybuses) as well as the closure of most petrol stations. Several such critical situations have arisen in recent years:

- 31 March 2015 - Ankara, Istanbul and 44 of Turkey's 80 provinces were without electricity for several hours. In Istanbul and Ankara, they shut down the metro and trams, leaving households and large industrial complexes without electricity. Traffic lights did not work, causing even more chaos on traditionally crowded roads in Turkish cities. There were also long lines at gas stations, where people came to buy diesel for generators. The power outage affected the lives of about 20 million people. Airports also reported a problem. As many as 11 of Istanbul's 16 air towers could not operate [7].
- 4 August 2019 - A major power outage hit the Indonesian capital Jakarta and its suburbs. The several-hour blackout affected tens of millions of people. In some neighbourhoods of the metropolis of Jakarta with millions of people, traffic lights went out and traffic in the city collapsed. They also had to evacuate passengers from trains in the city's new metro system [8].
- 9 August 2019 - an extensive blackout in Britain, traffic lights did not work and traffic collapsed. The state railway carrier Network Rail informed that in a number of areas all signalling devices lost power. All trains were stopped until the backup signalling system started [9].

The increased risk of failures and material damage in electricity transmission and distribution systems and thus adverse impacts on the operation of transport infrastructure is largely caused by the impact of increasingly frequent extreme weather events such as hail, wind disasters, landslides, etc. According to the Global Risks Report 2020, extreme weather events are the 1st risk by likelihood and the 5th risk by impact over the next 10 years [10]. In this context, mitigating the adverse effects of climate change, reducing society's vulnerability and increasing societal resilience by raising public awareness of climate change and building a knowledge base for more effectively adapting society to the adverse effects of climate change is becoming one of the biggest challenges today.
4. The Impact of Electromobility on Increasing Society's Dependence on Electricity

The number of electric vehicles in the world is growing rapidly and research and development of new technologies is advancing as well. According to The International Energy Agency (IEA), the number of electric vehicles in the world will increase from 5.1 million in 2018 to 130-250 million in 2030. They will consume 640-1,110 terawatt hours of electricity and save half of CO2 emissions (from the production of this energy) compared to the emissions of the same number of vehicles with internal combustion engines. This forecast includes not only passenger cars and light commercial vehicles, but also buses and lorries [11].

At the end of 2018, 1,570 electric vehicles were registered in Slovakia, of which 619 were plug-in hybrid (PHEV) and 951 were battery-electric vehicles (BEV). In addition, 74 light commercial vehicles and 47 electric buses were registered in 2018. In addition to BEV and PHEV, there are more than three thousand hybrid electric vehicles with an internally charged battery (HEV) registered in the Slovak Republic. The current historical trend suggests that the number of electric vehicles in the vehicle fleet of the Slovak Republic may reach 28,000 to 41,000 in 2030. The demand for electricity for the propulsion of electric vehicles in 2030 will be 220 - 710 TJ, which is less than 1% of the total electricity consumption in the Slovak Republic in 2018. If the increase in the number of electric cars is more progressive, e.g. 116,000 electric vehicles (5% of current passenger cars) in 2030 the equivalent of 2% of current electricity consumption for propulsion would be needed [11].

The transition to electromobility will increase society's dependence on electricity. The key task will therefore be to ensure the safety, security, stability and efficient management of the electricity transmission system, which will be important in the case of simultaneous charging of a larger number of electric vehicles in households in densely populated areas.

5. Indicators of Transport Vulnerability to Power Failure

The term vulnerability is defined differently in the professional literature depending on the authors background and the sphere of application. Hofreiter defines vulnerability as the property of any material object, technical device or social entity to lose the ability to perform its natural or established function as a result of external or internal threats of varying nature and intensity; expresses the degree of its ability to withstand external and internal threats [12].

In the Terminology Glossary of Crisis Management, vulnerability is defined as a complex feature reflecting the weaknesses of the system, its reduced resilience to possible disruption of its function, damage or destruction; it also expresses the degree of damage to the system in the event of a dangerous phenomenon [13].

Urbancova deals with the issue of assessing the vulnerability of key elements of railway transport in her dissertation. According to Urbancova, the assessment of the vulnerability of elements in railway transport consists in the assessment of the level of their vulnerability and the ability to restore their function after the accident. For the purposes of the dissertation, an algorithm for assessing the vulnerability of key elements was created, which consists of seven consecutive steps, namely: definition of the area of interest, identification (selection) of key elements located in the area of interest, description of key elements, identification of key element vulnerabilities, key element vulnerability analysis, calculation of the vulnerability of elements, identification of the most vulnerable elements of the area, calculation of the total vulnerability of the area of interest and subsequent protection of key elements [14].

The aim of this paper is to identify indicators of transport vulnerability in terms of services provided against power outages, which can be used to quantify the vulnerability of transport infrastructure in terms of services provided and thus improve emergency preparedness, which are often very dangerous and unpredictable. This issue is part of the solution of the project VEGA grant 1/0371/19 Societal vulnerability assessment due to failure of important systems and services in the electricity sector, where the responsible solver of the project is the author of the paper. When defining vulnerability, the author proceeds from the approach to defining vulnerability, which she applied within the FP7 project RAIN, based on 3 key factors (Fig. 1) [15]:

- **Exposure** - exposure of the system to the threat and its specific effects.
- **Susceptibility** - the susceptibility of the system to be damaged by a specific action.
- **Adaptive capacity** - the ability and capacity (resources) of the system to adapt to changing conditions and be better prepared to deal with adverse events and impacts.

![Fig.1 Vulnerability core factors](image-url)
This approach is based on the fact that the real effect of a power outage depends not only on its intensity, but also on whether elements, that are negatively affected by this event, are present in the affected system. The real effects of a given event and their severity are also determined by the ability of the system to anticipate the impact of the event in question (be prepared for it), react to it and adapt to the change, or the ability to mitigate and compensate damage.

The indicators proposed within the individual core factors describe the specific characteristics of the transport system in terms of the services provided, which are significant in terms of the system's vulnerability to power outages. The mentioned indicators are the subject of research and were proposed within the above-mentioned solution VEGA grant 1/0371/19, while the solution of the problem itself is not finished yet and the discussion is still ongoing (Fig. 2).

### Fig. 2 Proposal of indicators for assessing the vulnerability of transport in terms of services provided against power outages

By evaluating the Vulnerability Indicators and integrating them within the Vulnerability Core Factors, we get the final value of the Vulnerability index.

### 6. Conclusions

One of the priorities of the transport policy of the Slovak Republic is the security protection of transport infrastructure and means of transport, the aim of which is to ensure that employees, facilities and equipment, means of transport and information systems critical to the functioning of the society do not cease to fulfil their function under any risk and threat scenarios.

In the case of the activation of the threat of a significant disruption of the functionality of the transport infrastructure, it is necessary to take measures to ensure the normal operation of the economy and the protection of the population. In the area of transport, the return of the transport system to a stable state enabling the provision of transport services must be ensured, thus ensuring the renewal of potential elements of CI. Such measures are best processed in the economic mobilization plan according to Act no. 179/2011 Coll. Based on this Act, the Ministry of Transport, Construction and Regional Development of the Slovak Republic has also adopted a methodological guideline, which regulates the temporary renewal of railway and road infrastructure.

### Acknowledgements

This work has been supported by VEGA grant No. 1/0371/19 named “Societal vulnerability assessment due to failure of important systems and services in electricity sector” and the FP7 project No. 608166 “Risk Analysis of Infrastructure Networks in response to extreme weather”.

### References


7. Turkey was hit by a blackout. There was no metro, no planes and no lights in the apartments [online cit.: 2020-04-23]. Available from: https://dennikn.sk/88377/turecko-postihol-blackout-nejazdilo-metro-nelietali-lietadla-v-bytoch-sa-nesvietilo/

8. Collapse of traffic and extensive evacuation of the city: Jakarta and the surrounding area were hit by an extensive blackout [online cit.: 2020-04-23]. Available from: https://www.interez.sk/kolaps-dopravy-a-rozsiahla-evakuacia-mesta-jakartu-a-okolie-postihol-rozsiahly-blackout/

9. Britain was hit by a large-scale blackout. The traffic lights were angry, the traffic was collapsing [online cit.: 2020-04-24]. Available from: https://www.idnes.cz/zpravy/zahraniaci/londyn-blackout-elektrina-proud-vypadek.A190809_192337_zahranicni_hmo


Degradation of Equipment and Material in Long-Term Storage

J. Stodola1, Z. Krobot2, A. Breznicka3, J. Jelinek4, P. Stodola5

1University of Defence Brno, Kounicova Str. 64, 661 10 Brno, Czech Republic, E-mail: jiri.stodola@unob.cz
2University of Defence Brno, Kounicova Str. 64, 661 10 Brno, Czech Republic, E-mail: zdenek.krobot@unob.cz
3Alexander Dubcek University of Trencin, Pri parku Str. 19, 911 06 Trencin, Slovak Republic, E-mail: alena.breznicka@tnuni.sk
4University of Defence Brno, Kounicova Str. 64, 661 10 Brno, Czech Republic, E-mail: josef.jelinek@unob.cz
5University of Defence Brno, Kounicova Str. 64, 661 10 Brno, Czech Republic, E-mail: petr.stodola@unob.cz

Abstract

The article deals with selected practical problems of technical conditions of long-term stored equipment, its groups and materials in terms of state reserves, armed forces, etc. In addition to the issue of warehouses, the paper briefly presents the process of preparing the equipment and material for long-term storage and analyzes the example of a group of equipment (special vehicles engine) stored for a very long time. Its technical condition has been massively degraded after more than 20 years until it becomes completely unusable without overall repair.

KEY WORDS: material reserves, long-term storage, preservation, technical condition, reliability, failure intensity, UTD-20 engine

1. Introduction – Basic Terms

To deal with potential crisis situations in the state sphere, resources and services are available that can be used to immediately benefit the population and infrastructure affected by the crisis. These means and services must be available for emergency survival of the population, for the support of the integrated rescue system, state administration activities, etc. [1]. An important part of the system of economic measures for crisis situations is the area of state material reserves, which, according to the purpose of their use, are divided into material reserves, mobilization reserves, emergency stocks and supplies for humanitarian aid. The Administration of State Material Reserves provides many tasks such as storage, protection, replacement, procurement and control. The basic requirements for the equipment and material in terms of corrosion and aging protection are relatively strict in the legislation. The equipment and material are supposed to be in a state for immediate use upon removal from storage. In technical terms, these requirements are in some cases impossible to meet. An example is the long-term storage of special equipment and materials in the armed forces. The reason is the massive degradation of functional parameters caused especially by corrosion mechanisms. It turns out that the basic factors that determine the specific technical condition are the technology and quality of storage, storage process, performing prescribed procedures during storage and systematic inspection during storage. These are the selected basic terms related to the area:

- corrosion: physico-chemical interaction of the material and environment leading to changes in properties that cause the deterioration of the material, environment or technical system function, of which the material and environment are components;
- long-term storage: a set of technical and organizational measures to ensure long-term temporary anti-deterioration protection of armaments, equipment and materials for no less than 5 years [2];
- preservation: the activity required to protect the systems and equipment, whether installed or stored, in order to maintain them in a satisfactory condition (temporary preservation of materials associated with the use of preservatives);
- temporary protection: protection against corrosion applied over a period of time given by protective effects of the used means and the temporary protection system; temporary protection is used, for example, during the storage and transport of metal products or when the equipment is shut down;
- warehouse: a complex of buildings or storage areas, provided with storage equipment (see Table 1 for the characteristics of warehouses);
- storage: preservation of technical life of products and their combat readiness in the warehouse by carrying out a set of technical and organizational measures to prepare for storage and technical maintenance during storage;
- (material) ageing: a summary of irreversible changes in product properties over time due to climatic, chemical, thermal and other influences;
- corrosive aggressiveness: the ability of the environment to cause corrosion in a given corrosion system (see Table 2 for the classes of corrosive aggressiveness).

Note:
The basis for determining corrosion aggressiveness for individual metals is the level of pollution (5 classified intervals) and the wetting time in hours per year or in % of exposure.
The characteristics of warehouses

<table>
<thead>
<tr>
<th>Part of warehouse</th>
<th>Category</th>
<th>Corrosive agents in warehouses</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open spaces</td>
<td>1</td>
<td>A summary of all climatic and biological factors for a given area</td>
<td>Open space, a platform of a wagon or a car</td>
</tr>
<tr>
<td>Shelter</td>
<td>2</td>
<td>A summary of all climatic and biological factors for a given area, without the presence of sunshine or atmospheric precipitation</td>
<td>Semi-enclosed shelter, tent, product packaging, shelter under a sail</td>
</tr>
<tr>
<td>Unheated warehouse</td>
<td>3</td>
<td>A summary of all climatic and biological factors for a given area, without the presence of sunshine or atmospheric precipitation, temperature and humidity fluctuations are lower, the effect of corrosive active substances is weakened</td>
<td>Closed unheated rooms with natural ventilation and thermal insulation</td>
</tr>
<tr>
<td>Climate controlled warehouse</td>
<td>4</td>
<td>A summary of all climatic and biological factors is substantially weakened due to artificial regulation of values within a given range</td>
<td>Heated warehouses and rooms, containers with dynamic dehumidification, air conditioning</td>
</tr>
</tbody>
</table>

The classes of corrosion aggressiveness

<table>
<thead>
<tr>
<th>Class</th>
<th>Corrosive aggressiveness</th>
<th>Class</th>
<th>Corrosive aggressiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Very low</td>
<td>C2</td>
<td>Low</td>
</tr>
<tr>
<td>C3</td>
<td>Middle</td>
<td>C4</td>
<td>High</td>
</tr>
<tr>
<td>C5</td>
<td>Very high</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The equipment and material are stored in compliance with technological procedures that are chosen to ensure that the utility value of the equipment and material is maintained throughout storage [4-6], which is enabled in particular by:

- suitable storage in the required type of warehouse in a suitable storage area;
- appropriate protection against the effects of corrosion-climatic events, biological agents and mechanical damage;
- rational storage of the equipment in warehouses with regard to its use, designation, records and control;
- maintenance and inspection of the equipment during storage.

Rational storage provides visually well-arranged storage of material and equipment, easy technical and records control and rapid use as specified. [7]. The equipment and material must be stored under specified storage conditions to ensure that the required utility value is maintained, storage guarantee periods must be specified, as well as their possible tolerances. When storing the equipment, its quality is influenced mainly by internal and external climatic parameters, and their changes together with biological influences. The basic parameters include in particular:

- temperature and its changes (± 1°C);
- relative humidity of air and its changes (± 5%);
- air pollution and its intensity (sulphur oxides, nitrogen oxides, chlorides, sulphates, airborne dust, etc.);
- surface electrolyte and its intensity (wetting);
- solar radiation and its intensity;
- wetting time [3];
- macro and micro biological agents (fungi, insects, rodents, etc.).

When selecting a store, it is necessary to know the climatic characteristics of the storage area, Table 1 and hence the possibility of determining the stress intensity and the storage time. Stress intensity is indicated by the degree of corrosive aggressiveness of the atmosphere, Table 2. The nominal values of selected climatic factors are determined according to Table 3.

The nominal values of selected climatic factors

<table>
<thead>
<tr>
<th>Climate type</th>
<th>Min. temp. °C</th>
<th>Max. temp.</th>
<th>Wetting period hr/yr</th>
<th>Classification of wetting interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>cold</td>
<td>-33</td>
<td>+34</td>
<td>2500 to 4200</td>
<td>$\tau_4$</td>
</tr>
<tr>
<td>mild</td>
<td>-20</td>
<td>+35</td>
<td>2500 to 5500</td>
<td></td>
</tr>
</tbody>
</table>

Note:
$\tau_4$ indicates the classified wetting interval by the wetting time in hours: $2500 < \tau \leq 5500$ or in %: $30 \leq \tau \leq 60$ for all climatic areas.
2. Warehouses and Storage Areas

The deployment of warehouses is designed to provide protection against the effects of climatic and corrosive agents, against deterioration, theft, fire, explosion or similar events. The placement of warehouses determines the loading work, transportation handling and storage procedures. The warehouses must not be located in flood areas and in areas where the intensity of corrosion-climatic stress significantly exceeds the required parameters (marshes, water areas, industrial agglomerations, etc.). Warehouse constructions and entrance areas provide protection against the penetration of surface water, snow, rodents and insects into the warehouse and also comply with fire safety requirements [7].

Long-term storage technology (preservation)

Long-term storage primarily involves the protection of metal products against corrosion; these operations are:
- surface preparation;
- use of preservatives;
- use of packaging materials and
- packing in transport packaging.

The initial operation is the removal of all impurities, degreasing and drying of the surfaces, or their passivation. The inner surfaces of the products (mechanisms, cavities, fuel and cooling systems, etc.) are not specially cleaned prior to preservation. Dirt is removed by draining the operating fluids after the products have been put into operation. If the purity of internal surfaces of the systems is of particular concern, after the operating fluid has been drained, the cavities are rinsed with organic solvents, mineral oil of low viscosity or the same operating fluid.

Preservative and packaging means are specially certified commodities [8], e.g.: preserving oils, greases, fats, waxes, sensing and scouring coatings, desiccants, contact and evaporation inhibitors, paraffin or waxed papers usually with evaporator inhibitor, inert gases for use in hermetic packaging, antimicrobial agents for the protection of non-metals, anti-sticking agents for packaging non-metals, polyethylene coatings, PVC foils, containers, boxes, etc. The basic methods of preservation technology are: dipping, spraying, coating, pouring, filling, aerosol use and use without direct application to the surface.

Barrier means are also important; they generally include unsealed, sealed, watertight and sealed hermetic systems whose microclimate of enclosed spaces has been treated.

Theoretical work and practice show that despite the very systematic standards describing the organization and technology of long-term storage in detail, the technical condition deteriorates significantly after repeated storage, i.e. after a period longer than 5 years. The main causes of technical deterioration are standard corrosion processes and aging of non-metallic materials (seals, rubbers, plastics, and other plastic parts). Microbial corrosion of metals attacking copper pipes, aluminium parts, iron-based parts (Cladosporium mould), also plays a role. The corrosion of ferrous metals can be divided into aerobic (oxygen) and anaerobic (without oxygen) corrosion. However, these two types can be combined and support each other in different conditions. The most common is aerobic corrosion in the form of relatively simple iron rusting.

3. Experimental Assessment of Technical Conditions

The experiment was based on a qualified assessment of the technical condition of the combustion engine UTD-20 and its individual parts, Fig. 1, its repairability and serviceability. The UTD-20 engine is a standard drive unit of the late 1980s, very advanced and reliable at the time [9]. At present, however, this construction is outdated, obsolete, but still used after modernization, as a power unit and mechanical power source for special vehicles.

Engine block (crankcase, cylinder blocks, cylinder liners)
- crankcase and blocks without apparent damage, the condition corresponds to the age;
- the cylinder liners are heavily attacked by corrosion, Fig. 2, on the outside at the seal location; the inner part with no visible traces of wear; hard carbon traces in the place of the seal ring, probably the run-in remains in the manufacturing plant.

Fig. 1 View of UTD-20 engine
Crankshaft, camshaft and balance shaft
- a crankshaft with small corrosion marks on the seal; the functional surface at the location of the inner and outer rod is slightly wavy, but its cause cannot be clearly identified. It can be caused by imperfect production technology or abrasive wear (particles and debris) during run-in;
- cam and balancing shafts, conditions correspond to the age, there are no signs of corrosion or other wear on the surface.

Engine pistons
- on engine pistons there are probably hard carbon debris that indicate relatively low temperature during engine running-in and also corrosion traces that are likely to be caused by piston ring corrosion.

Valves, valve seats
- the conditions of the valves and the valve seats correspond to the age and show no signs of wear or damage.

Fig. 2 Detail of extensive corrosion attack on cylinder liners

Fig. 3 Example of damaged seal

Gear wheels
- gear wheels with slight signs of incipient corrosion, without any visible damage.

Internal and external connecting rods
- the conditions of the connecting rods correspond to the age, no signs of wear or damage.

Bearings
- at first view no obvious damage or wear, conditions correspond to the age.

Seals, rubber hoses
- I note that this engine uses iron-asbestos (suction pipe) and copper-asbestos (exhaust pipe) pads, which should not be currently used;
- all rubber parts are completely damaged (hardened, brittle on touch, frayed), completely unusable for operation, Fig. 3.

Suction and exhaust pipes
- both pipes are heavily corroded.

Fuel system
- the injection pump that does not allow moving the fuel dispensing components, dysfunctional equipment with corrosion changes of the control device, corrosion of pistons and partly of rollers was found with the decisive parts;
- injector leakage, incipient corrosion and increased thermal wear products;
- the fuel system of the engine being inspected has the original fuel injection nozzle, which is no longer in use;
- conditions of the feed pump, pipes and fuel cleaners correspond to the age.

Other parts and systems
the components of the lubrication and cooling systems (cleaners, pump, etc.) correspond to the age, completely non-functional rubber parts; the bearings are movable, but some are attacked with incipient stage of point corrosion.

The set of special-purpose wheeled vehicles was rated as complex, repairable, serial or partially serial-parallel systems designed for long-term use, which are subject to a number of failures during use. The failures intensity is the basic variable characterizing the reliability (more accurately failure-free condition) of the monitored vehicles. It is characterized by the failure intensity that is defined.

4. Conclusions

Based on the above information about the condition of individual parts of the engine being inspected, it can be stated that the engine in question is not capable of standard operation; it cannot be started, e.g. on the engine brake or directly in the vehicle. The reason is massive corrosion wear, aging of seals and rubber parts (hoses) and malfunctioning of several important systems, e.g. the injection pump, etc. The cause of this condition is an excessively long storage period, probably unsuitable storage with temperature changes and especially the failure to perform the prescribed maintenance (revision RE-10), etc. The most substantial fact is that it was an extraordinarily long storage period, i.e. from the time of production to the time the assessment was performed (approximately 30 years). The engine as a whole requires a relatively demanding diagnostic repair [10], replacement of many parts and components [10-14]; complete replacement of all rubber and other parts, as well as replacement of non-ecological seals containing asbestos. It is noted that a refurbishment of the fuel overflow is necessary. The engine in question is repairable but some corroded and otherwise worn parts are unusable and irreparable.

Acknowledgement

Presented work has been prepared with support of the project MOBAUT (DZRO K-202), University of Defense Brno, Czech Republic

References

Is Hazard Perception Related to Risk Taking Attitudes and Intentions?

J. Slavinskienė¹, A. Endriulaitienė², L. Šeibokaitė³, R. Markšaitytė⁴

¹Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: justina.slavinskiene@vdu.lt
²Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: aukse.endriulaitiene@vdu.lt
³Vytautas Magnus University, Jonavos 66-330, Kaunas, Lithuania, E-mail: laura.seibokaite@vdu.lt
⁴Vytautas Magnus University, Jonavos 66-328, Kaunas, Lithuania, E-mail: rasa.marksaityte@vdu.lt

Abstract

Hazard perception (HP) skills of road users are acknowledged as an important contributors to accident involvement. Cognitive abilities, driving experience, or executive functions are discussed as the major correlates of this skill in traffic safety literature. However, the relationships between hazard perception and individual differences or beliefs of drivers are under-investigated, although they might contribute to the HP training effectiveness or explanation of safety outcomes. This study aimed to explore the relations between self-evaluated road hazard perception skills, risk taking attitudes and intentions to drive in a risky manner. Ninety-nine university students (72 females; 27 males; mean of driving experience 5.3 years, frequency of driving at least once per month) participated in a cross-sectional study. Hazard perception skills were measured using a six-item self-report scale [19]. The questionnaire also contained the Scale of Intentions to take Driving Risks by Ben-Ari, Florian, Mikulincer [3] and the Risk-taking attitudes scale by Ulleberg & Rundmo [18]. Data analyses revealed statistically significant gender differences. Males reported better hazard perception skills, more risky speeding attitudes and more intentions to risk while driving than females. Self-evaluated hazard perception skills were positively correlated to riskier attitudes towards drinking and driving, but not related to intentions in males. Hazard perception skills were negatively correlated to intentions of risky driving and positively to attitudes towards joyriding in females. Better self-evaluated hazard perception skills might be the risk factor for both male and female drivers’ road safety attitudes, whereas better self-reported hazard perception skills might be the protective factor for female drivers’ intentions. Still, these contradictory results should be tested in future studies with not self-report measures and in larger samples.

KEY WORDS: self-reported road hazard perception skills, risk taking attitudes, intentions to take driving risks

1. Introduction

According to WHO, road traffic crashes remains a serious public health concern all over the world due to 1.25 million deaths each year [20]. Eighty percent of road traffic deaths occur in middle-income countries, which account for 72.2% of the world’s population [13]. Even more, some scientists indicate that road crashes are indeed the major cause of death among young people, with the most vulnerable group being represented by people between 15 and 29 years [5]. The driving task is very complex and requires not only vehicle control or driving skills, but also emotional-behavioral and cognitive skills. Thus, psychological antecedents of road crashes or dangerous driving among young drivers remain an important issue.

Perception of the various driving situations complexity and accurate assessment of various hazards while driving is found to be significant psychological aspects for safe behavior on the road [4]. So, recently the analysis of various cognitive skills becomes particularly relevant. One of the multidimensional, complex cognitive process is hazard perception. This is the process of detecting, evaluating and responding to dangerous events on the road that have a high likelihood of leading to a collision [6]. The ability to identify hazardous situations while driving is an important skill, which enables the driver to overcome complex cognitive demands that the traffic environment dictates [4]. So the main object of this paper is hazard perception skills.

Previous findings indicated that young, inexperienced drivers have lower hazard perception skills, they detect fewer hazards and have longer response latencies than older and more experienced drivers [1, 16]. It was found that males compared to females have a propensity to underestimate the potential hazards of driving, which leads to a riskier driving style [16]. So, previous studies reveal individual differences in hazard perception skills. However, most researchers focus on hazard perception peculiarities in relation to demographic information of different road users groups. There is a lack of studies with a more comprehensive analysis of hazard perception. In other words, there is little information about hazard perception relationship to other psychological factors which explain why drivers behave dangerously while driving.

Theory of Planned Behavior is one of the most commonly used theories to explain risky behavior. To this theory, positive attitudes (affective and cognitive evaluation of the situation, people and etc.) form the higher intentions to behave (willingness and readiness to put the efforts to perform certain actions) and when a real behavior appears [2]. In a risky driving context, the relation between positive risk taking attitudes and higher intentions to drive in a risky manner is well established among various road users groups [7, 11, 13]. However, scientists agree that the Theory of Planned Behavior needs a more extensive perspective when the relation between attitudes and intentions could be...
explored together with other psychological factors that might be improved by training [7]. An extension of the theory is needed to justify the assumption that improved hazard perception skills by training result in greater sensitivity to actual or potential risk while driving. This may enhance the possibility to reconsider possessing road safety attitudes that may result in higher intentions to adopt safer behavior strategies while driving. Even though better hazard perception skills were found to be correlated with attitudes towards safe driving [7], still these relations are under-investigated, especially when considering individual differences. So, this study aimed to explore the relations between self-evaluated road hazard perception skills, risk taking attitudes and intentions to drive in a risky manner.

2. Method

Participants. Ninety nine university students (27 males and 72 females) participated in a cross-sectional study. Age differences between males ($M_{age}$ 24.04 years, SD 4.46); and females ($M_{age}$ 24.30 years, SD 6.85) were non-significant ($F(99) = 1.04, p = .855$). All participants reported similar, at least 3 months of driving experience (for males $M_{dr. experience}$ 5.35 years, SD 3.44; for females $M_{dr. experience}$ 5.35 years, SD 5.64). Also, 66.7% of males and 38.9% of females reported driving on a daily basis.

Participants were invited to participate in this study as volunteers. Written informed consent was obtained from all participants, who were informed about study aims, ethical issues, and data protection.

Instruments. The questionnaire was designed to measure self-reported hazard perception skills, risk taking attitudes and intentions to risk while driving. Demographic data (gender, age, driving experience and driving frequency) was collected as well. Hazard perception skills were measured by six-items, on the seven-point Likert scale (from 1 to 7) [19]. Higher scores indicated better hazard perception skills. Internal consistency of scale (Cronbach $\alpha$ was .93. Information about risk-taking attitudes was obtained from the 25-item Risk-taking attitudes scale by Ulleberg & Rundmo [18]. Five-point Likert scale (from 1 to 5) measured six types of self-reported risk-taking attitudes: attitude towards speeding (5 items; Cronbach $\alpha = .79$), drinking and driving (3 items; Cronbach $\alpha = .68$), traffic flow vs. rule obedience (9 items; Cronbach $\alpha = .83$), attitude towards violation of traffic rules (2 items; Cronbach $\alpha = .81$), showing off driving skills to others (3 items; Cronbach $\alpha = .60$), and attitudes towards joyriding (3 items; Cronbach $\alpha = .55$). Higher scores of the total as well as individual sub-scales indicated more risk-prone attitudes. The internal consistency of the general scale was .86. Also, a 10-items self-reported Likert scale (from 0 to 11) of Intentions to take Driving Risks [3] measured how likely respondents would risk on the road in various situations. Higher scores of this scale indicated higher intentions to take driving risks. Internal consistency was sufficient for further analysis: Cronbach $\alpha$ was .71.

All scales were translated into Lithuanian using standard back-forward translation procedures.

Statistical analysis. Data were analyzed with the help of the IBM SPSS 17.0 Statistical Package. The Kolmogorov – Smirnov test was used and this analysis revealed the normal distribution of all scales. Therefore parametric statistics (Student’s t-test and Pearson’s correlational analysis) were applied.

3. Results and Discussion

To identify whether there are gender differences in hazard perception skills, risk taking attitudes and intentions Student's t-test was applied. Means and standard deviations presented in Table 1 showed statistically significant gender differences. As it was expected [12], males reported higher risk taking attitudes (general scale) ($p = .041$), specifical attitudes towards speeding ($p = .005$). These results may imply that males tend to be not enough sensitive to risk as well as to underestimate the probability and severity of risks caused by dangerous acts like speeding. Similarly to previous studies [7, 14], males reported higher intentions to take the driving risk, but also better self-evaluation of hazard perception skills. These findings support the idea that males detect and respond in time and appropriately to potentially dangerous events on the road more than female drivers [1]. However, males more than females tend to dominate and compete with other drivers on the road [15]. By dominating and competing, males more than females intend to take risks while driving and ignore the potential consequences of dangerous driving.

<table>
<thead>
<tr>
<th>Psychological variable</th>
<th>Sample</th>
<th>$F$ ($df$, model $p$)</th>
<th>Mean ± St. deviation</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard perception skills</td>
<td>Males</td>
<td>2.16 (99), .005</td>
<td>33.07 ± 5.25</td>
<td>.006</td>
</tr>
<tr>
<td>Risk taking attitudes (general score)</td>
<td>Females</td>
<td>1.16 (99), .02</td>
<td>29.53 ± 6.26</td>
<td>.041</td>
</tr>
<tr>
<td>Attitude towards speeding</td>
<td>Males</td>
<td>.057 (99), .003</td>
<td>68.74 ± 15.16</td>
<td>.005</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>16.78 ± 4.64</td>
<td>61.74 ± 13.60</td>
<td>.005</td>
</tr>
<tr>
<td>Attitude towards drinking and driving</td>
<td>Males</td>
<td>3.68 (99), .08</td>
<td>13.71 ± 4.72</td>
<td>.058</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>5.04 ± 2.53</td>
<td>4.11 ± 1.97</td>
<td>.006</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>19.58 ± 12.66</td>
<td>.08</td>
<td></td>
</tr>
</tbody>
</table>
Further results are presented for males and females separately due to previously found differences. Correlational analysis (presented in Table 2) revealed that better self-reported hazard perception skills were positively associated with riskier attitudes towards drinking and driving in the male samples. No significant relations were found between males’ hazard perception skills and intentions to take driving risks. In the females’ samples, better self-reported hazard perception skills were significantly related to riskier attitude towards joyriding. However, only in the females’ group better self-reported hazard perception skills were significantly correlated to weaker intentions to take risks while driving.

Although previous findings showed that higher hazard perception is associated with safer attitudes towards traffic safety [7, 13], the results of the current study (Table 2) are inconsistent but supporting contrary relation. It was found that self-evaluated hazard perception skills are related to a riskier attitude towards drunk driving in the males groups and to a riskier attitude towards joyriding in the females groups. Even though high correlational coefficients were found in the males group, the level of statistical significance was not reached probably due to a quite small sample size (n of male respondents = 27).

The interpretation of these results should be complex. Based on previous studies, the majority of drivers overestimate their own driving skills and abilities to drive when the evaluation is based on self-report [17]. Since hazard perception skills were measured by self-evaluation method in this study, it could be assumed that respondents possess a greater subjective feeling of higher ability to handle any kind of hazards under any conditions. It is likely that inaccurate self-evaluation have a negative effect for a cognitive and emotional evaluation of risky driving. This means that drivers, who overestimate driving skills, usually have an attitude that they can handle dangerous driving situations more efficiently than other drivers [17]. Thus, males with better self-evaluated hazard perception skills, possess insufficient and inadequate evaluation of drunk driving behavior. Also, highly confident drivers usually are less able to perceive how alcohol impairs their driving performance, they are unable to perceive probability to experience negative consequences of drunk driving. Thus these over-confident male drivers possess more positive attitude towards drunk driving [9]. Also, results showed that subjective evaluation of having better hazard perception skills relates to more positive attitude towards joyriding in a females group. This imply that higher confidence to handle any kinds of hazards interferes with an adequate evaluation of seriousness of excitement seeking by risky driving. Females are likely to perceive risky driving as more beneficial than harmful in order to feel excitement while driving [9]. So, in general,
presented findings indicate that better self-evaluated hazard perception skills could be a risk factor for risky attitudes possession.

Lastly, results showed that better self-evaluated hazard perception skills are significantly related to lower intentions to take driving risk but only for female drivers. Previous studies revealed that those female drivers, who have better self-evaluated hazard perception skills, possess a higher threshold for reacting to potential hazards in real driving [1]. It is likely that more accurate response to hazards is a result of greater awareness and concentration while driving. All these aspects might enhance greater willingness and readiness to put the efforts to perform safer driving. As the result, compared with males, female drivers possess higher driving responsibility and they easily adopt the preventing behavior while driving. In conclusion, better female drivers’ self-evaluated hazard perception skills might be treated as a protective psychological factors from intentions to drive in a risky manner.

4. Conclusions

The results of this study confirmed that better self-evaluated hazard perception skills relate to riskier attitudes towards some dangerous actions while driving for both male and female drivers. However, bigger confidence in own hazard perception skills is related to higher intentions not to take risks while driving in a group of female drivers. These results imply that only female drivers who possess better hazard perception are more likely to be cautious and careful in their behavior. Also, results imply that better hazard perception skills do not enhance drivers’ attitudes to abide by traffic rules and to follow responsible, safe driving. Thus, promoting safe driving is a complex process while not only hazard perception skills, but also risk taking attitudes should be improved by training.

Acknowledgements

The study has received funding from the Research Council of Lithuania (LMTLT), agreement No. S-MIP-19-1.

References

15. Oppenheim, I; Oron-Gilad, T.; Parmet, Y.; Shinar, D. 2016. Can traffic violations be traced to gender-role,


Aspects of the Use of Motor Vehicles in the Intervention Activities of Private Security Services in a Selected Region

Z. Zvaková¹, R. Mendel²

¹University of Žilina, Univerzitná 8215/1, 01026 Žilina, Slovakia. E-mail: zuzana.zvakova@fbi.uniza.sk
²University of Žilina, Univerzitná 8215/1, 01026 Žilina, Slovakia. E-mail: mendel@advokat-mendel.sk

Abstract

Private security services represent a specific trade segment. Private security services are characterized by continuous development that is linked to the security situation. Another specific feature of the private security area is that many people are employed in this area. The development in the area of private security affects the socio-economic development of individual regions in Slovakia. In 2018, there were 24,453 persons in charge of physical protection in the field of private security. By comparison, there were only 2,541 municipal policemen in Slovakia in 2018.

The operation of the alarm receiving centre is one of the basic activities of private security services. This activity involves the obligation to immediately check the alarm signal. The operator must take into account the effectiveness of the different methods of signal verification. Verification of the signal must meet the statutory criteria, be profitable and performed within a period agreed in the contractual relationship. The time it takes to control the alarm signal is one of the competitive factors of the ability of the alarm receiving centre operators, and therefore the choice of the appropriate transport means is one of the key issues of operators' economic efficiency.

The paper is focused on the comparison of the possibilities of checking the alarm state with the use of a selected single track and two-track motor vehicle. The authors focus on the costs of operators, the legal aspects of the choice of means of transport and the advantages or disadvantages of selected motor vehicles for private security. The findings are presented in the model situation within the traffic situation of the city of Žilina.

KEY WORDS: economic aspects, legal aspects, transport means, intervention, private security services, alarm receiving centre

1. Introduction

The area of private security services in Slovakia is regulated by the Private Security Act and the relevant decrees to this Act [1]. The most well-known and at the same time the most operated type of private security service is the guard service [1, 2]. In addition to the protection of persons and the protection of property, guard service operators also deal with the protection of transport or the protection of property and persons during transport, the elaboration of a protection plan and the operation of a centralized protection desk [3]. This article focuses on the last of these options, the private security services operating the centralized security desk and their capabilities to verify the alarm signal.

The Private Security Act imposes an obligation on operators of private security services to immediately verify the alarm condition by at least two professionally qualified persons or by a security camera system [4, 5]. This law also exhaustively stipulates how the vehicle is to be marked. These motor vehicles must be marked in black on a white background with the text "EMERGENCY VEHICLE", in English, the designation SECURITY is appropriate. The inscription on the vehicle must be placed on both sides of the vehicle and the rear of the vehicle and consist of capital letters. Motorcycles must be appropriately marked [1]. The law therefore also allows the use of motorcycles in private security. The article is a response to this possibility and to the observed trend, which means that private security services are beginning to use motorcycles in their intervention activities.

2. Private Guard Services in Slovakia

Statistics on the activities of private security services in Slovakia are kept by the Ministry of the Interior of the Slovak Republic, specifically the Office of Private Security Services of the Presidium of the Police Force (SR). Each private security service is obliged to submit to the Office of Private Security Services of the Presidium of the Police Force (SR) a report on activities for the previous calendar year by 31 January [1]. Each report on the activities of the private security service has a descriptive part and a statistical part. The content of the report is to provide the Ministry of the Interior of the Slovak Republic with information on cases [1]:

- the using of the weapon by security staff;
- the using of a weapon against a security employee;
- the killing of a security staff member;
- the killing of a person by a security staff member;
- personal injury to a security staff member;
- personal injury to security staff;
727

- detection of a criminal offence by security staff;
- committing a crime by security staff;
- restrictions on the personal liberty of a person caught in a criminal offence;
- concluding a contract for the provision of security services.

Based on these data, the Office of Private Security Services of the Presidium of the Police Force (SR) publishes a report on the activities of private security services in Slovakia. These statistics are wide in scope but are not ideal for our needs. The reports do not include information on the number of centralized protection desks in Slovakia or on the intervention activities of security services operating centralized protection desks. Interventions by members of private security services are presented through the use of a weapon or security device, restrictions on personal liberty, etc.

In Slovakia, the number of operators of private security services has been stable for a long time. The number of private security operators has not fallen below 3,000 since 2009 and has not exceeded 3,600. Of the total number of private security services, private security services make up approximately 18.9%. The share of private security services in the total number of private security services has ranged from 20% to 17% since 2009, with a slightly declining trend.

The development of the number of private security services in Slovakia since 2009 is shown in Fig. 1. The current number of private security services and private guard services in individual self-governing regions is in Fig. 2.

![Fig. 1 Number of valid private security services licenses by [6]](image1)

![Fig. 2 Number of valid private security services licenses in 2018 in Slovak self-governing regions by [6]](image2)

The number of operators of private security services in self-governing regions is subject to the same trend as the national development. In addition to the overall state of operation of private security, the overall development of individual regions and on-going business and investment activities have a significant impact on the deployment of private security services.

3. Possibilities of a Private Guard Service to Check the Alarm State

The private guard service is responsible for the protection of the object according to the contract it has concluded with the client. The legislation sets out the obligations of the service operator as well as restrictions on activities. The
following provisions have a significant impact on intervention [1]:
- It is forbidden to provide a private guard service in a way that raises concerns that it will be misused to violently influence political disputes, collective bargaining between employees and employers, as well as to any suppression of rights and freedoms.
- Guards may not use any method of face masking when performing tasks under this Act.
- Guards must not be used on vehicles with special warning signs.
- Before concluding the contract, the operator must make sure that the person with whom he is concluding the contract is entitled to use the subject of protection.
- The operator of the centralized protection desk is obliged to check the alarm condition via a camera system or at least two professionally qualified persons.

The activity of private guard services is, in addition to the legal regulation, also limited by a contract (between the guard service and the client). The security service may not carry out its activities outside the interest protected by the contract.

The private guard service has two ways to check the alarm condition:
1. Check the alarm condition via the camera system (CCTV) [7]. In this case, the operator decides whether the verification using the camera system is sufficient to refute or confirm the breach of security of the protected object. After confirming an intervention is initiated and the Police Force is contacted.
2. Check the alarm condition without the use of CCTV, only by guards. The procedure is similar to the previous point (inspection of the object - intervention - contacting the Police Force).

The law stipulates that the verification of the alarm signal should be immediate. Immediate verification of the alarm signal is its verification in the shortest possible time. From this point of view, the use of CCTV is appropriate to meet the condition of immediate verification. However, there is a problem with the fact that not every object that is connected to the centralized security desk is also protected by CCTV. It is also not possible to say with certainty that the verification of the alarm signal by CCTV is always possible and always successful.

The legislation allows the use of motor vehicles or motorcycles [8]. There are no statistics on the types of motor vehicles or motorcycles in private security. However, based on observations and experience from membership in the Slovak Chamber of Private Security, we can state that security services use more two-track motor vehicles, but at the same time there are private security services using motorcycles. These security services present the use of motorcycles as a benefit that will allow them to respond flexibly and check the alarm in a short time.

The main advantages of using a motorcycle are as follows:
1. The dimensions, weight and construction of the motorcycle allow better manoeuvrability then using the car.
2. The motorcycle has smaller dimensions, which makes parking easier.
3. Lower procurement and operating costs (procurement costs, taxes and fees, insurance, servicing, fuel consumption) [8].

The main disadvantages of using a motorcycle are the following:
1. Dependence on the weather - frost and rain are not suitable conditions for riding motorcycles. The guard service is not a seasonal matter, therefore in the conditions of the Slovak Republic, it is not possible to provide private security service only with motorcycles.
2. Higher demands on the skills of driving guards. The safety of all road users is paramount [9, 10].

We will show the possibilities of checking the alarm state [12, 13] on a specific example. A model example is the verification of the alarm state indicated on the centralized protection desk in the UNIZA Science Park. The protected object is the Faculty of Security Engineering UNIZA. Only the main transfer routes are in the illustration (Fig. 3). We neglected possible side detours (through the housing estate, parking places, etc.).

The length of the transfer routes, the number of critical points [14] and the expected maximum and minimum transfer time are shown in Table. Critical points have been identified by long-term observation of the traffic situation. In determining the maximum and minimum transfer times for car and motorbike, the specificities of each critical point and the flexibility of the means of transport have been taken into account [15]. The minimum transfer time was set as the transfer time without delay at intersections and traffic restrictions and in compliance with road traffic legislation. The maximum transfer time was determined as the average travel time along the route at peak times, again in compliance with road traffic legislation.

Table

<table>
<thead>
<tr>
<th>Route</th>
<th>Route length [km]</th>
<th>Number of critical sites</th>
<th>Car</th>
<th>Motorbike</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max. transfer time [min.]</td>
<td>Min. transfer time [min.]</td>
</tr>
<tr>
<td>Route A</td>
<td>3.3</td>
<td>5</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td>Route B</td>
<td>4.9</td>
<td>2</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Route C</td>
<td>4.8</td>
<td>3</td>
<td>25</td>
<td>7</td>
</tr>
</tbody>
</table>
The minimum transfer time is the same for both means of transport, as it is the transfer time without delay at the maximum permitted speed. In practice, this time is unrealistic, but reaching it is closer when riding a motorcycle.

4. Conclusions

Comparing the possibilities of using motorcycles and cars in private security is very subjective. To determine the main advantages and disadvantages, it is necessary to assess the external and internal factors influencing a particular situation (security situation or trade situation of private security provider) [16]. A motorbike can be more advantageous, especially if the private guard service operates in a city with a complicated traffic situation or guards several objects in a specific area, e.g. in the historic city centre, or in areas such as housing estates and residential areas, where there is a complicated road network and problematic parking. On the other hand, the use of motorcycles in private security has disadvantages. One of the main disadvantages is the inability of using them throughout the year, due to the influence of the weather and thus the need to own cars and motorcycles. This increases the overall cost. Another significant disadvantage is the requirements for the capabilities of guards as well as the requirements for their safety [17].

To examine the trend towards the use of motorcycles in private security, it would be necessary to have statistics available and to carry out an extensive survey. Despite the absence of such data, it is clear that motorcycles are starting to be used in private security and that operators are using these vehicles as a method of alarm verification and as a tool to increase competitiveness.

Acknowledgement

This paper was supported by project VEGA 1/0768/19.

References


10. Soltes, V.; Kubas, J.; Stofkova, Z. 2018. Education as One of the Indicators of Quality of Life, 12TH International Technology, Education And Development Conference (INTED), 6849-6855.


What is the Way Forward? Or What Kind of Challenges the Engine Manufacturers of International Aviation Industry Have to Face

B. Varga\textsuperscript{1}, L. Kavas\textsuperscript{2}, K. Beneda\textsuperscript{3}

\textsuperscript{1}National University of Public Service, H- 5008 Szolnok, P.O.B. 1., Hungary E-mail: varga.bela@uni-nke.hu
\textsuperscript{2}National University of Public Service, H- 5008 Szolnok, P.O.B. 1., Hungary E-mail: kavas.laszlo@uni-nke.hu
\textsuperscript{3}Budapest University of Technology and Economics, H-1521 Budapest, Pf. 91, Hungary E-mail: kbeneda@vrht.bme.hu

Abstract

Public awareness and political concern about the environmental impact of the growth of civil aviation has grown significantly over the past 30 years. First the noise, later the air pollution and today the carbon dioxide emission. This is not overridden by the fact that today the international aviation industry, like all sectors of the economy, is severely affected by the COVID-19 pandemic, which may temporarily overshadow the previous challenges. We all seen the visible change of international airspace in March, April and May 2020, but life is expected to return to its normal way in one or two years and although the crisis may shake the industry, serious issues in international aviation remain the same. The most important, as it was mentioned, is the rising value of CO\textsubscript{2} emissions in the light of climate change, regarding the 5 percent per year growth rate of aviation. This article presents the difficulties faced by aircraft engine manufacturers today regarding the engine efficiencies, which have one of the closest relations to the CO\textsubscript{2} emission, supported by theoretical background information.

KEY WORDS: Gas Turbine Engine, Bypass Ratio\textsuperscript{1}, Thermal Efficiency, Propulsive Efficiency, CO\textsubscript{2} Emission, Climate Change

1. Introduction

From the chemical reaction of carbon hydrogens assuming perfect and clean combustion, carbon dioxide and water vapor are produced. Of course, that happens in gas turbine engine combustors, too. However, the combustion is not perfect in the combustors of gas turbine engines, so other combustion products (pollutants) are also generated like nitrogen oxides, sulphur oxides, carbon monoxide, soot, unburnt fuel particles. The emission of these pollutants can be reduced by optimizing the combustion process improving the fuel nozzles and combustor itself. These pollutants are responsible for the ground-surface pollution and significant in the vicinity of airports, but ICAO\textsuperscript{2} has been pushing ever stricter regulations from the 1960s to reduce these pollutants.

On the other side 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. 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 the atmosphere. However, regarding climate change the main "enemy" is carbon dioxide. Each tonne of burnt fuel produces approximately 3.1 tonnes of carbon dioxide.

Carbon dioxide emissions due to certain forms of human activity, based on the EDGAR database created by the European Commission and Netherlands Environmental Assessment Agency released in 2015 is 36,061.71 million tons. Other even more potent greenhouse gases, for example, methane, are not included in this data. 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% \cite{1}. Today there is some even more pessimistic opinion, which says that the aviation grew strongly over the past decades (1960–2018) in terms of climate change impacts, with CO\textsubscript{2} emissions increased by a factor of 6.8 million to 1034 million tons \cite{2}. Considering the expected growth rate of aviation, this amount of emitted carbon dioxide would be triplicated in the next 30 years without additional measures.

Of course, it is not easy to even grasp these enormous numbers but easier to think an average airliner we generally travel with and a rough estimation for its one-year carbon dioxide emission. This aircraft consumes 1.4-1.5 kg kerosene in every second, accordingly produces roughly 4.5 kg of carbon dioxide. That kind of aircraft spends

\textsuperscript{1} Bypass ratio: in a turbofan engine the ratio of the mass flow rate of the bypass duct to the mass flow rate of the core.
\textsuperscript{2} ICAO: International Civil Aviation Organisation, a UN specialized agency in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector.
minimum of 12 hours from 24 hours in the air every day and says about 300 days in a year (if less its operation is not economical). The production of this average (rather underestimated) use is $4.5 \times 3600 \times 12 \times 300 = 58,320,000$ kg, or 58,320 tons of carbon dioxide.

This is the reality, despite the fact that there has been significant technological progress in the aviation sector, as the fuel consumption per passenger-kilometres of today manufactured aircraft decreased by about 50% compared to the 1960s. Of course, it was resulted in several novelties, for example, the winglets which improved the fuel efficiency by 3-5%, but the gas turbine engines have had an especially huge role in fuel efficiency improvement. For example, the specific fuel consumption (sfc) of Rolls Royce gas turbine engines more than halved from 1958. Unfortunately, in the near future we cannot expect a huge breakthrough in this field and that is the reason the aviation industry has to think about a complex measurement package to rein its ever increasing carbon dioxide emission. To achieve ICAO's global aspirations, namely the Carbon Neutral Growth of International Aviation a package of measures was set, which includes:

- the technological requirements of both the engine and the airframe structure (Aircraft Technology);
- traffic developments, both for ground operations and for air traffic controlling (Operational Improvements);
- the use of Sustainable Alternative Fuels and Market Based Measures (MBMs)\(^1\) \([1, 3]\).

Despite the complex program, it is certain that improving the efficiency of engines will continue to be one of the most effective means of reducing CO\(_2\) emissions. But how are we doing in this field at the moment and what opportunities we have?

### 2. Efficiencies of Aircraft Propulsion Systems

Before we turn to discuss efficiencies, let’s define what an aircraft propulsion system is. All aircraft propulsion system is a unit of two sub-systems namely the engine and the propulsor. Engines, mostly heat engines, implement the well-known thermodynamic cycles, like Otto, Diesel or Brayton. The propulsor (propeller, fan, nozzle), which accelerates some kind of working fluid (air, the hot exhaust of heat engine or both of them). The result is thrust, a mechanical force, which is generated through the reaction of accelerated a mass of gas, as explained by Newton's third law of motion. In accordance with it both two components have efficiencies, namely the thermal efficiency of the heat engine and the propulsive efficiency of the propulsor. There are several different types of propulsion systems, but which is most responsible for CO\(_2\) emission, is the high bypass ratio turbofans due to their extensive use in commercial aviation, see Fig. 1. However, turboprops are also frequently used for short range hauls, their share in CO\(_2\) emission comparing to turbofans is negligible.

![Fig. 1 High bypass ratio turbofan engine [4]](image)

The heat engine component of this propulsion system (core or gas generator unit) is a gas turbine engine, implements the Brayton cycle, while the propulsor is partly the fan stage, partly the nozzle. We have to underline, that about 85% of the thrust is a product of the fan stage so it is the main subject of our interest regarding the propulsive efficiency.

### 3. Thermal Efficiency

The Kelvin–Planck statement (or the heat engine statement) of the second law of thermodynamics states that it is impossible to create a cyclically operating device, which absorbs heat from a single thermal reservoir and delivers an equivalent amount of work. It means that due to the second law of thermodynamics part of the heat is rejected, but unfortunately, some more heat is dropped due to the component losses. Practically the thermal efficiency of heat engines is the percentage of heat that is transformed into work.

We usually define a thermal efficiency for a given operational condition mostly for take-off rate of power. Manufacturers usually provide a number of data for a given gas turbine engine (thrust, fuel consumption, compressor pressure ratio, turbine inlet temperature, mass flow rate), but least the thermal efficiency. This can be determined in several ways, for example with thermodynamic cycle calculation using the above-mentioned data which are usually given for 0 m altitude by the International Standard Atmosphere (ISA)\(^2\) (288 K, 101325 Pa). There is another simple

\(^1\) Market Based Measures have been initiated by the ICAO as the main tool of CORSIA (Carbon Offsetting and Reduction Scheme of International Aviation) project.

\(^2\) International Standard Atmosphere (ISA): common reference values of temperature, pressure, density and speed of sound at various altitudes.
method that uses the law of energy conservation to examine the energy of the working fluid entering and leaving the engine and, in the meantime, the heat which is transferred to the engine. In this case, this heat is introduced into the system by burning fuel in the combustor. The chemical energy of the burnt fuel (heat) increases both the kinetic energy and the internal energy of working fluid. Part of the heat, which increases the internal energy of the working fluid is waste heat regarding the engine performance, meanwhile, the other part is converted into work (actually work flow, called jet power [W]), see Fig. 2.

Fig. 2 Energy balance of a gas turbine engine

Calculating the thermal efficiency a sample engine was chosen with the next performance data:

- Take-off thrust without afterburner ($F$): 54 kN
- Mass flow rate ($\dot{m}$): 68 kg/s
- Fuel consumption ($\dot{m}_{\text{fuel}}$): 1.27 kg/s
- Fuel heating value ($FHV$): 42,845 MJ/kg

Using these values, the exit velocity ($v_e$) of the hot gas from the nozzle is 794 m/s (1), of which the jet power is 21.43 MW (2). The input heat flow from the fuel burnt in the combustor is 54.41 MW (3). The quotient of the two gives a thermal efficiency of 39.5%. This can be considered realistic, taking into account the turbine inlet temperature (1721 K) and the compressor pressure ratio (27.5:1) of the examined engine. This was also confirmed by the thermal model I developed earlier, and using the following efficiency data, compressor polytrophic efficiency: 0.86, expansion efficiency: 0.88, burner efficiency: 0.97, total pressure loss: 0.94, mechanical efficiency, including power oftake: 0.97 gave a similar thermal efficiency of around 40%, see Fig. 3, blue point. It should be noted that the above calculated thermal efficiency is only valid for the take-off rate of power, at a lower rate of power the thermal efficiency always decreases due to lower turbine inlet temperature and compressor pressure ratio, see Fig. 3.

Assuming an engine test, the flight speed ($v$) is equal to zero. Calculated from the thrust and mass flow rate the exit velocity ($v_e$) of the hot gas from the nozzle is 794 m/s (1), of which the jet power is 21.43 MW (2). The input heat flow from the fuel burnt in the combustor is 54.41 MW (3). The quotient of the two gives a thermal efficiency of 39.5%. This can be considered realistic, taking into account the turbine inlet temperature (1721 K) and the compressor pressure ratio (27.5:1) of the examined engine. This was also confirmed by the thermal model I developed earlier, and using the following efficiency data, compressor polytrophic efficiency: 0.86, expansion efficiency: 0.88, burner efficiency: 0.97, total pressure loss: 0.94, mechanical efficiency, including power oftake: 0.97 gave a similar thermal efficiency of around 40%, see Fig. 3, blue point. It should be noted that the above calculated thermal efficiency is only valid for the take-off rate of power, at a lower rate of power the thermal efficiency always decreases due to lower turbine inlet temperature and compressor pressure ratio, see Fig. 3.

Assuming an engine test, the flight speed ($v$) is equal to zero. Calculated from the thrust and mass flow rate the exit velocity ($v_e$) of the hot gas from the nozzle is 794 m/s (1), of which the jet power is 21.43 MW (2). The input heat flow from the fuel burnt in the combustor is 54.41 MW (3). The quotient of the two gives a thermal efficiency of 39.5%. This can be considered realistic, taking into account the turbine inlet temperature (1721 K) and the compressor pressure ratio (27.5:1) of the examined engine. This was also confirmed by the thermal model I developed earlier, and using the following efficiency data, compressor polytrophic efficiency: 0.86, expansion efficiency: 0.88, burner efficiency: 0.97, total pressure loss: 0.94, mechanical efficiency, including power oftake: 0.97 gave a similar thermal efficiency of around 40%, see Fig. 3, blue point. It should be noted that the above calculated thermal efficiency is only valid for the take-off rate of power, at a lower rate of power the thermal efficiency always decreases due to lower turbine inlet temperature and compressor pressure ratio, see Fig. 3.

Assuming an engine test, the flight speed ($v$) is equal to zero. Calculated from the thrust and mass flow rate the exit velocity ($v_e$) of the hot gas from the nozzle is 794 m/s (1), of which the jet power is 21.43 MW (2). The input heat flow from the fuel burnt in the combustor is 54.41 MW (3). The quotient of the two gives a thermal efficiency of 39.5%. This can be considered realistic, taking into account the turbine inlet temperature (1721 K) and the compressor pressure ratio (27.5:1) of the examined engine. This was also confirmed by the thermal model I developed earlier, and using the following efficiency data, compressor polytrophic efficiency: 0.86, expansion efficiency: 0.88, burner efficiency: 0.97, total pressure loss: 0.94, mechanical efficiency, including power oftake: 0.97 gave a similar thermal efficiency of around 40%, see Fig. 3, blue point. It should be noted that the above calculated thermal efficiency is only valid for the take-off rate of power, at a lower rate of power the thermal efficiency always decreases due to lower turbine inlet temperature and compressor pressure ratio, see Fig. 3.
Several different categories of gas turbine categories have been developed since the beginning gas turbine era (1940s), see Fig. 4 and there are significant differences among their average thermal efficiencies. The relatively small helicopter turboshafts have the worst efficiency with 20–30%, turboprops 25–40%, turbojet 25–40%, low bypass ratio turbofans 40–45%, high bypass ratio turbofans can reach 40-50% thermal efficiency by the available data and my calculations. The relatively large differences in each category may be justified by age differences, different technological developments and differences in size. Size is extremely important, which is in some way even justifies the efficiency differences of different categories. Practically a smaller size punishes the gas turbine engines through worse component efficiencies. Examining the related researches in this field it became clear that the compressor blade length has a significant effect on compressor polytrophic efficiency. In smaller engines the shorter compressor blades deteriorate the compressor polytrophic efficiency [5].

Generally, the thermal efficiency is a function of the temperature range of the thermodynamic cycle and the engine component efficiencies. If the ambient (lowest) temperature is fixed at 288 K (ISA, 0 m altitude) practically depends on the highest temperature of the cycle (turbine inlet temperature). The turbine blade cooling, with which the turbine inlet temperature can be increased improving the thermal efficiency, has an otherwise negative side effect, namely the cooling air extraction from the compressor eats some of this possible thermal efficiency increment. Consequently, improving cooling efficiency or (and) the blade alloys’ heat resistance also has a positive effect on thermal efficiency.

Back to the component efficiencies, producing parameter sensitivity examination, we can realise that all engine component efficiencies and losses influence the thermal efficiency but their influence is different. Here we try to reflect how significantly each one effects it. In Fig. 5 it can be seen one example for 1800 K turbine inlet temperature. Initial values of engine component efficiencies and losses are in the top left corner of Fig. 5.

At first, each component efficiencies and losses was worsened individually by 1% and the deterioration of the efficiency (first row and the related blue columns represent the specific network output which is not subject of our examination at the moment) are also given in [%] (brown and green colour as the relative ($\eta_{rel}$) and absolute($\eta_{abs}$) change of thermal efficiency) in Fig. 5. It is clearly evident that the gas turbine engines are especially sensitive for the compression and expansion of polytrophic efficiencies regarding their thermal efficiency, consequently improving them inevitably to increase the thermal efficiency. It is clear from the Figure that 1% change either in compression ($\eta_{polc}$) or expansion ($\eta_{exp}$) polytrophic efficiency induces about a 0.5% change in thermal efficiency. Regarding the other component losses, burner efficiency ($\eta_{b}$), pressure loss ($\sigma$) and mechanical efficiency ($\eta_{m}$) there is not much room to improve them, and on the other hand, their effect on the examined thermal efficiency is smaller.
So far, thermal efficiency has been examined at 0 km/h speed and 0 m altitude by ISA state variables. As the flight speed and altitude increases, the thermal efficiency of gas turbine engines increases significantly. This is especially true for the high bypass turbofan engine of an airliner, of which both cruising speed and altitude are very typical. Significantly most of their operations is carried out in a narrow range of altitude (9–11 km) and Mach number (0.78–0.84). Take, for example, an average cruising altitude of 10,000 m and a Mach number of 0.82. At this Mach number and altitude two effects improve thermal efficiency. One is the decreasing temperature with altitude. At this altitude, the ambient temperature is 223 K, which is much cooler than the standard 288 K at sea level. This improves the thermal efficiency by increasing the temperature range of the thermodynamic cycle, where the highest temperature is the turbine inlet temperature meanwhile the lowest is the ambient temperature. The other is the ram air pressure, which in the case of the above mentioned Mach number produces an air intake pressure ratio of 1.5:1. In this conditions, the total pressure ratio of a high bypass ratio turbofan can reach the value of 75:1 pushing the working point at a given turbine inlet temperature to the direction of the higher thermal efficiency, which in this case can near 60% thermal efficiency regarding the most outstanding high bypass ratio turbofan engines. However, at lower efficiency and pressure ratio, but this effect can be presented in Fig. 3, see red points.

4. Propulsive Efficiency

The propulsive efficiency is a quotient of effective power ends up on the aircraft body to move it forward, and jet power which is produced by the heat engine (gas generator). After some transformation of equation 4, it is visible that if the acceleration of the working fluid (with other words specific thrust, $v_f - v_0$) is high, the propulsive efficiency is low.

$$\eta_{prop} = \frac{2v_f}{(v_f - v_0) + 2v_0}. \quad (4)$$

In Fig. 6 we see the propulsive efficiency curves of different gas turbine categories. Chosen a certain speed it is clear that for a given thrust it is the best way to increase the mass flow rate to decrease the acceleration of the working fluid. That is the reason why the bypass ratio of airliners rose continuously practically from 0 reaching today the value of 11–12 (CFM Leap engine).

Fig. 6 Propulsive efficiency of different aircraft gas turbine engines [4]

However, selecting a particular speed is pointless because it is worth to evaluate it at the airplane’s actual cruising speed. Regarding airplanes powered by pure turbojets and low bypass ratio turbofans have a certain cruising speed, but due to their various military tasks, it is not typical to hold this speed except long distance flying. But both turboprops and especially the airliners powered by high bypass ratio turbofans the flying altitude and speed very typical, which means, regarding their somewhat different bypass ratio the propulsive efficiency is about 65–75%.

5. Overall Efficiency

Overall efficiency is the product of thermal and propulsive efficiencies. In Fig. 6 it is shown how the thermal, propulsive and overall efficiency depends on the Mach number regarding a multirole combat aircraft with a low bypass ratio engine, which was calculated for 0 m altitude (own calculation). At higher altitude, the thermal efficiency curve would be a little bit higher (+3–4%). What is important still that to the right of the red point (M > 1) the curve is theoretical because the aircraft simply cannot reach a higher Mach number without afterburner, which highly decreases its thermal efficiency. What is sure from Fig. 6 that the examined aircraft (engine) never in any conditions can produce higher overall efficiency than this 20–25%. Any other than cruising speed and altitude gives less thermal efficiency.
What is the average overall efficiency? We would be able to make good estimation after a long time examination of their flight profiles, but I guess the all operation average is well below 20%. Airliners due to the typical flying altitude and speed spend most of their flying hours close to their best thermal and propulsive efficiency, which presuming an average 55% thermal and 70% propulsive efficiency produces 35% overall efficiency. Consequently, their average overall efficiency is somewhere between 30–40%.

Fig. 6 The overall efficiency of a low bypass ratio engine

6. Conclusion

Considering the evaluated efficiencies there is considerable room for improvement even in commercial aviation whose engines produce the best overall efficiency. Unfortunately, almost sure we cannot wait for a single breakthrough. Some researchers envision up to 30% overall efficiencies growth over the next few decades. I see little chance of that. Improving the compressor and turbine polytrophic efficiency, increasing the cooling efficiency of the turbine blade cooling may result in some percent. Regarding the materials, the Ceramic Matrix Composites are very promising because they have higher temperature capability than current high pressure turbine superalloys. The new additive manufacturing not directly, but through the weight reduction also can contribute for the better fuel consumption. Regarding the propulsor increasing the bypass ratio is difficult because it increases the engine diameter causing the problem even to place the engine not to mention the caused extra drag. However, the higher bypass ratio can be the result of a smaller core which assumes greater specific network output. But the smaller size frequently causes less component efficiencies. This means that each effect must be weighed on a pharmacy scale to reach a minor step forward.

What is sure the ICAO makes a very significant effort to rein the ever increasing CO₂ emission of the international aviation industry and a hard push will be on the engine manufacturers for every single tenth of a percent increase in fuel efficiency.

Acknowledgment

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.

References

1. Why ICAO decided to develop a global MBM scheme for international aviation [online cit.: 2020-08-02]. Available from: https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ1.aspx
3. Climate Change [online cit.: 2020-08-02]. Available from: https://www.icao.int/environmental-protection/pages/climate-change.aspx,
5. Varga, B.; Békési, L. 2014 "Tényleg nem a méret számít?", avagy hogyan bünteti a kis méret a helikopter "turboshaft" hajtóműveket, Repüléstudományi Közlemények, XXVI, pp. 81-93
Loyal Locally vs. Loyal Globally: Comparative Study of Brand Value Sources in Contemporary Automotive Market

J. Majerova¹, L. Gajanova², M. Nadanyiova³

¹University of Zilina, Faculty of Operation and Economics of Transport and Communications, Department of Economics, Univerzitna 1, 010 26, Zilina, Slovak Republic, E-mail: jana.majerova@fpedas.uniza.sk
²University of Zilina, Faculty of Operation and Economics of Transport and Communications, Department of Economics, Univerzitna 1, 010 26, Zilina, Slovak Republic, E-mail: lubica.gajanova@fpedas.uniza.sk
³University of Zilina, Faculty of Operation and Economics of Transport and Communications, Department of Economics, Univerzitna 1, 010 26, Zilina, Slovak Republic, E-mail: margareta.nadanyiova@fpedas.uniza.sk

Abstract

Brand loyalty is the topic that has been traditionally discussed not only in the scope of theory but also in the realm of practice of brand value building and managing. Its controversial nature lies in the fact that there is a strong impact of noneconomic aspects of consumer behaviour on its creation and maintenance. The psychographic nature of brand loyalty reflects the quality of interpersonal relations in society in general. Thus, the construction of models relevant to the effective brand loyalty building and management is not only a matter of econometric, but much more psychological approach application. Hence, the aim of this paper is to compare the car brands' rankings in worldwide perspective and in the Slovak Republic, applying apparatus relevant to the identification of brand loyalty sources which are significant for Slovak socio-cultural profile as they have been highlighted in own previous research. In the case study of Slovak consumer perception of brand loyalty sources in the scope of the automotive industry, it is possible to verify far formulated postulates and modified theories that take into account the relevance of national psychographic specifics. Secondary data comparing world car brands rankings were obtained from the Statista as a leading business data platform. Primary data used in the presented study were obtained by our own survey carried out on a sample of 2000 respondents (citizens of the Slovak Republic older than 15 years). The given data were statistically evaluated by the factor analysis supported by the implementation of the KMO Test, Barlett's test of sphericity and calculation of Cronbach's Alpha for relevant car brands loyalty sources. The discrepancies in brand value rankings worldwide and in the Slovak Republic have been found as well as the need for consideration of national psychographic specifics in the process of brand loyalty building and managing in conditions of the automotive industry represented by car brands has been verified.

KEY WORDS: brand, brand value, car brand, automotive market, brand loyalty, psychographic aspects

1. Introduction

The need to provide revision of traditional strategic concepts with emphasis on behavioral approach has been the leading motive to offer an analysis of consumers' perception of brand value sources. This was the basic prerequisite of our research in which we have found that specifics of the national socio-cultural profile affect the priority of the components of subjectively perceived brand value sources. The importance of brand value sources has been in specific conditions of the Slovak Republic identified for car brands as following: 1) benefits, 2) imageries, 3) attitudes, and 4) attributes [1]. However, we have highlighted the fact that these research outcomes are fully applicable only in the case of the Slovak market and specifics of the socio-cultural profile of Slovak consumers. Thus, the view of comparison between Slovak preferences and world trends in the automotive market would enrich this finding. Managerial implication of such an approach lies in the basic knowledge platform for erudite decision making in the scope of brand value building and management on transnational markets.

2. Literature Review

The research of automotive brands has been expanding recently. However, scientific attention is mainly paid to the issue of sustainability highlighting the trend of electric vehicles as well as focusing on sustainable brand management in its procedural prospective [2, 3]. Long et al. state that within the extensive literature on consumer research of battery electric vehicles (BEVs), the role of brand perceptions is neglected. Consumers may gravitate towards automotive brands that they are accustomed to ("brand loyalty"), or they might prefer a new brand (i.e. Tesla) for being new and innovative ("pioneer brand advantage"). Further, BEV-supportive policies may indirectly favor or disfavor the BEVs produced by a given brand. They explore consumer perceptions of automotive brand perceptions in general, and, for the specific case, of Tesla. Respondents most frequently associate BEVs with Tesla (27%), Toyota (27%), and Chevrolet (26%). Over two-thirds of respondents are familiar with Tesla, and 40% select Tesla as a brand representing the "future of BEVs". Their exploratory findings indicate the potential importance of brand in shaping
consumer perceptions of BEVs [4]. They develop the theory of Axsen et al. who focused on the role of lifestyle in shaping consumer behaviour regarding novel low-carbon technologies, stating that some patterns are consistent across lifestyle segments, where most participants emphasized the practicality of plug in electric vehicles, the improved driving experience and overall interest in environmental protection. However, motivations varied, some corresponding with participants' lifestyle engagement; for example, participants that engaged in pro-environmental lifestyles were more likely to emphasize the environmental aspects of plug in electric vehicle usage [5].

Shieh et al. followed the trend of research in the scope of sustainable brand management and they proved 1) positive and significant effects of green advertising design on purchase intention, 2) positive and remarkable effects of environmental attitude on green advertising design, and 3) positive effects of environmental attitude on purchase intention [6]. Similarly, Karlsson and Skold focused on managerial challenges in the scope of branding processes and patterns and they showed that managing manufacturing corporations with multiple brands is not just on a scale between full specialization and full commonalization but instead has its own logic of categorizations and portfolio formations. To develop the value of the brand portfolio, management must simultaneously embrace and address a number of highly integrated corporate values and highly differentiated brand company values [7].

The tendency to establish the theory of relevant brand value sources on the automotive market has recently also been significant – mainly in the scope of quality and traditional Aaker brand equity concept [8]. Hanaysha indicated that service quality has a significant positive effect on brand equity. Furthermore, service quality has a significant positive effect on all dimensions of brand equity: brand awareness, brand loyalty, brand image, and brand leadership [9]. Kovacs shows how the analysis of brand associations can help to elaborate on the cognitive position of a brand by comparing brand associations of Hungarian consumers in two product categories - automobiles and alcoholic drinks [10]. According to Akdeniz and Calantone, the impact of marketing signals on performance is higher when the quality of a brand is perceived as higher than its actual quality [11].

However, these brand value sources have been analyzed mainly in general, applying a general approach to the automotive market without considering national socio-cultural specifics. The trend of the need of implementing such a wide perspective has been stated recently by various authors [12-14]. Following this, Soviar et al. analyzed the reputation of the global automobile manufacturers primarily in the territory of the Slovak Republic for their comparison considering also the reputation of brands in the wider Central European context, global context has also been considered. The selected brands were Volkswagen, Toyota, KIA, and Peugeot. The findings of the article included a detailed analysis of the online reputation of examined individual brands as well as contained a list of the most important factors that can positively or negatively affect brand reputation [15].

Following the actual state of knowledge highlighted in the provided literature review we can identify the basic research problems: lack of knowledge about brand value sources discrepancies in the automotive market based on national socio-cultural specifics. According to this, the main aim of the paper is to compare the car brands rankings’ in a worldwide perspective and the Slovak Republic, applying apparatus relevant to the identification of brand loyalty sources which are significant for Slovak socio-cultural profile as they have been highlighted in own previous research. We assume that there are significant discrepancies in brand value ranking caused by different priorities in brand value sources of loyalty.

3. Methods and Data

Secondary data comparing world car brands' rankings were obtained from the Statista as a leading business data platform. Primary data used in the presented study were obtained by our survey carried out on the sample of 2000 respondents in the first quarter of the year 2020 (citizens of the Slovak Republic older than 15 years). The questionnaire survey was conducted using the method CAWI (Computer Assisted Web Interviewing) by an external agency. The main surveyed population was the population of the Slovak Republic aged over 15 years (acquiring legal personality according to valid Slovak legislation). The reason for such a limitation was the requirement to ensure the autonomy of purchasing decisions and the real reflection of the value of the brand in the economic behavior of the Slovak population. The structure of the surveyed sample was socio-demographically representative. In the light of the marketing implications of the questionnaire survey, we have compiled a questionnaire and filled the brand value sources (imageries, attitudes, attributes and benefits) with each relevant component [16]. These are summarized in Table 1.

Brand value sources subjectively perceived by Slovak consumers in the automotive industry (based on the Likert's scale) were statistically evaluated using factor analysis. Factor analysis is a multidimensional statistical method aimed at creating new unobservable variables, the so-called factors, which reduce and simplify the original number of data while retaining a substantial portion of the information [17]. Based on the results of factor analysis, we have been able to determine the connection among the individual brand value sources in the case of car brands. These data form the pillar for arguing the comparative analysis of car brands' rankings worldwide and in the Slovak Republic.
Table 1

<table>
<thead>
<tr>
<th>Brand value sources</th>
<th>Components of brand value sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>imageries</td>
<td>prestige</td>
</tr>
<tr>
<td></td>
<td>modernity</td>
</tr>
<tr>
<td></td>
<td>certainty</td>
</tr>
<tr>
<td></td>
<td>pleasure</td>
</tr>
<tr>
<td>attitudes</td>
<td>I aim to buy branded products</td>
</tr>
<tr>
<td></td>
<td>I am interested in branded products regularly</td>
</tr>
<tr>
<td></td>
<td>branded products attract my attention because I consider them better</td>
</tr>
<tr>
<td></td>
<td>branded products attract my attention because I consider them more prestigious</td>
</tr>
<tr>
<td>attributes</td>
<td>image</td>
</tr>
<tr>
<td></td>
<td>quality</td>
</tr>
<tr>
<td></td>
<td>popularity</td>
</tr>
<tr>
<td></td>
<td>modernity</td>
</tr>
<tr>
<td></td>
<td>creativity of ad</td>
</tr>
<tr>
<td>benefits</td>
<td>it makes me happier</td>
</tr>
<tr>
<td></td>
<td>it increases my social status</td>
</tr>
<tr>
<td></td>
<td>it makes it easier for me to get friends</td>
</tr>
<tr>
<td></td>
<td>it attracts the attention of others</td>
</tr>
<tr>
<td></td>
<td>it suits my lifestyle</td>
</tr>
</tbody>
</table>

4. Results and Discussion

Table 2 summarizes the results of Interbrand ranking 2019 relevant for the automotive market [18]. As it is visible, the top car brand is Toyota at the 7th place. Mercedes is the second most valuable brand according to this ranking (the 8th place). The trio of top car brands is finalized by BMW at the 11th place. It is interesting to observe, that almost all the brands acquire a positive shift in their brand value evolution. The exception are only Nissan (-6%), Kia (-7%) and Land Rover (-6%). These outcomes are relevant for further comparison of the world most preferred car brands (obtained from Statista) and Slovak most preferred car brands (own survey).

Table 2

<table>
<thead>
<tr>
<th>Car Brand</th>
<th>Rank</th>
<th>Brand value in m USD</th>
<th>Change in brand value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota</td>
<td>7</td>
<td>56,246</td>
<td>5%</td>
</tr>
<tr>
<td>Mercedes</td>
<td>8</td>
<td>50,832</td>
<td>5%</td>
</tr>
<tr>
<td>BMW</td>
<td>11</td>
<td>41,44</td>
<td>1%</td>
</tr>
<tr>
<td>Honda</td>
<td>21</td>
<td>24,422</td>
<td>3%</td>
</tr>
<tr>
<td>Ford</td>
<td>35</td>
<td>14,325</td>
<td>2%</td>
</tr>
<tr>
<td>Hyundai</td>
<td>36</td>
<td>14,156</td>
<td>5%</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>40</td>
<td>12,921</td>
<td>6%</td>
</tr>
<tr>
<td>Audi</td>
<td>42</td>
<td>12,689</td>
<td>4%</td>
</tr>
<tr>
<td>Porsche</td>
<td>50</td>
<td>11,652</td>
<td>9%</td>
</tr>
<tr>
<td>Nissan</td>
<td>52</td>
<td>11,502</td>
<td>-6%</td>
</tr>
<tr>
<td>Ferrari</td>
<td>77</td>
<td>6,458</td>
<td>12%</td>
</tr>
<tr>
<td>Kia</td>
<td>78</td>
<td>6,428</td>
<td>-7%</td>
</tr>
<tr>
<td>Land Rover</td>
<td>85</td>
<td>5,855</td>
<td>-6%</td>
</tr>
<tr>
<td>Mini</td>
<td>90</td>
<td>5532</td>
<td>5%</td>
</tr>
</tbody>
</table>

Fig. 1 shows the ranking of brands in the global automotive market in 2019 according to Statista. Toyota is the leading brand. According to this data, Toyota is also the most valuable brand. However, further, ranking varies significantly from the Interbrand 2019 outcomes. Chevrolet is not included in the Interbrand 2019 ranking despite it being one of the top brands according to the global automotive share perspective in 2019. Moreover, Mercedes and BMW have been ranked in significantly different places. While in the case of Interbrand 2019, these brands are the 2nd and the 3rd, in the case of Statista, these brands are at the end of the ranking. This state can be caused by the fact that the theory and practice of subjectively perceived brand value varies. It means that while the customer can mark brands as
subjectively valuable, the final buying decision can be different. Thus, it can be observed the impact of subconscious factors affecting buying decisions making. In such a case a phenomenon of brand loyalty plays a crucial role in the evaluation of the effectiveness of brand value building and management. Only those brands that are considered valuable by the loyal consumers are able to convert the subjectively perceived value into desired brand performance indicators.

Fig. 1 Global automotive market share in 2019 by brand according to Statista

Fig. 2 shows the ranking of the Top 10 most valuable car brands on the Slovak market in 2019 according to their own research. As it is obvious, the first place in this ranking is occupied by the car brand which has not even been included in the rankings of the world most valuable car brands. This fact is caused by strong a national inclination to the traditional brands and their historical heritage [19]. Surprisingly Audi is placed as the 2nd most valuable brand. This posture does not have any logical verification in comparison with world car brands rankings. Possible reasoning could lie in the fact that they both are members of one holding and its value is derived from the subjectively perceived value of car brand Škoda [20]. On the other hand, BMW confirms the results of Interbrand ranking 2019 relevant for the automotive market.

Fig. 2 Top 10 most valuable car brands on the Slovak market in 2019

The outcomes of the comparative overview of world and Slovak car brands in 2019 have indicated the need for deeper analysis of brand value sources in the automotive market. Previously provided factor analysis has shown that specifics of the national socio-cultural profile affect the priority of the components of subjectively perceived brand value sources. While traditionally, it has been discussed if the dominant source of car brand value is quality or image, it has been proven that in conditions of the Slovak Republic, both these characteristics are clustered into one factor – attributes, and this factor does not have a significant impact on brand value subjectively perceived by consumers. On
the contrary, this factor is the least important among all four factors, because the importance of brand value sources has been identified as follows: 1) benefits; 2) imageries; 3) attitudes and 4) attributes [1]. So, we can conclude that optimal branding strategy in the automotive market should be set on the basis of the main competitive advantage of car brand i.e. on subjectively perceived benefits (an increase of social status, facilitation of making friends, the attraction of attention of others, suiting the lifestyle) and not on quality or image as a main car brand attributes from a traditional point of view [9]. However, quality has been detected as the most affecting factor in the case of world car brand loyalty research. Fig. 3 shows leading factors in keeping consumers loyal to brands worldwide in 2019 according to Statista. As it is obvious, none of these factors is identical to subjectively perceived benefits which have been confirmed as dominant brand loyalty sources (an increase of social status, facilitation of making friends, the attraction of attention of others, belonging to the lifestyle).

Fig. 3 Leading factors in keeping consumers loyal to brands worldwide in 2019 according to Statista

The optimal solution of this managerial challenge seems to be the finding of intersection areas in the scope of individual components of brand value sources. Correspondence analysis between factors of brand value loyalty would be the optimal way to identify relevant components of "benefits" and "attributes" which could be used as a basis for coherent brand management in the automotive market [21, 22]. However, it is important to highlight the fact that presented research outcomes form a platform for informed managerial decision making only in specific conditions of the Slovak market. In all other cases, these findings should be critically re-evaluated taking into account national specifics of selected markets.

5. Conclusions

Leading motives of consumer buying behaviours are often hidden. Even not intentionally, consumers tend to deviate from their proclaimed attitudes when the final buying decision is made. It means that subjectively perceived brand value sources do not have to be also leading factors of buying decisions. The probability of the significant difference between attitudes and actions of consumers can be reduced by strengthening the phenomenon of brand loyalty. Thus, the aim of this paper was to compare the car brands' rankings in worldwide perspective and in the Slovak Republic, applying apparatus relevant to the identification of brand loyalty sources which are significant for Slovak socio-cultural profile as they have been highlighted in own previous research. In the case study of Slovak consumer perception of brand loyalty sources in the scope of the automotive industry, it is possible to verify so far formulated postulates and modified theories, which take into account the relevance of national psychographic specifics. Secondary data comparing world car brands' rankings were obtained from the Statista as a leading business data platform. Primary data used in the presented study were obtained by our survey carried out on a sample of 2000 respondents (citizens of the Slovak Republic older than 15 years). When applying this approach, the discrepancies in brand value rankings worldwide and the Slovak Republic have been found. It has been also verified that the need for consideration of national psychographic specifics in the process of brand loyalty building and managing in conditions of the automotive industry represented by car brands is present.

Acknowledgement

Contribution is a partial output of scientific project VEGA 1/0718/18: The impact of psychographic aspects of pricing on the marketing strategy of companies across products and markets.
References

Study of Braking Dynamics of Long and Heavy Trains on Track Downlines with a Curve

D. Valba¹, G. Bureika²

¹ AB “LTG Infra”, Geležinkelio 2, 02100 Vilnius, Lithuania, E-mail: darius.valba@litrail.lt
² Vilnius Gediminas Technical University, Saulėtekio 11, 10223, Vilnius, Lithuania, E-mail: gintautas.bureika@vgtu.lt

Abstract

The longitudinal dynamics aspects of the heavy and long train during braking is analysed in this research work. The braking systems of long and heavy trains are considered. The highest forces exerted on the couplings during braking are examined. Using the software package „Universal Mechanism“ the numerical simulation of the operation of the braking system of long and heavy trains is performed. The entire train length and the impact of using the type of train braking system on longitudinal forces value during braking processes are considered as well. The particularities of braking on track downlines with a curve of the long heavy trains are defined. Finally, basic conclusions are given.

KEYWORDS: railway transport, heavy long train, train longitudinal dynamics, train braking processes, numerical modelling

1. Introduction

More than 50 million tons of cargo is carried by the Lithuanian railways each year. To ensure the throughput of the infrastructure to transport larger quantities of cargo, more traction vehicles are needed in operation. Another alternative to increase the throughput is to form heavy commercial trains that are twice as long as conventional ones. In the case of pneumatic brakes, problems arise due to the stability of the train and the continuity of the braking process itself [1, 4]. The braking a long train due to the inertia of the actuation of the pneumatic system takes an additional few seconds. Thus, a doubling of their mass and length may lead to an increase in the pre-braking distance up to 2-3 times, precisely due to the duration of the actuation of the pneumatic brakes. Similarly, the action of braking and quasi-static inertial and gravity forces acts simultaneously on slopes with track curves thus creating a risk of the overturning and/or derailment of the train [2, 3].

For the simulation of longitudinal dynamics of heavy trains, software packages are used to calculate the forces exerted on the train during running and braking. The following software packages may be used to calculate the longitudinal forces on the train: VOCO, TsDyn, PoliTO, CARS, BODYSIM, UM, TDEAS, CRE-LTS and TABLDSS [5, 6]. MATLAB and TDA can be used to calculate the train dynamics.

Scientists and experts from different countries use the following criteria to assess the performance of different braking systems of long and heavy trains:

1) maximum allowable forces of different types of automatic couplings (hereinafter – AC) [7];
2) stability of wheel contact during braking in track curves [8];
3) durability of the track when braking long and heavy trains [8, 9];
4) braking time of long trains with different brake cylinders [9];
5) maximum permissible longitudinal forces acting on the AC of a train braked on the track curve [8].
6) braking force value when changing the performance parameters of the braking system [10].

This paper examines the course of the braking process of long and heavy trains. The problem is ensuring the safety of long and heavy freight trains during the process – is thus being solved, and the case study is braking the trains on slopes with curves. The development of a mathematical model for the braking long and heavy freight trains and the use of rolling stock dynamic packages allows assessing the conditions for ensuring the safety conditions and braking performance of long freight trains.

2. Simulation of Braking System Operation and Longitudinal Dynamics of Heavy Trains

The simulation of the operation of the pneumatic braking system (hereafter – PBS) and electric-pneumatic braking system (hereafter – EPBS) of the train is the initial stage of the investigation of the dynamics of the train braking process. A physical model of the forces exerted on the moving train is being developed (Fig. 1).

In the simulation, each rail car is considered to be a concentrated mass. These masses are combined through stiffness and suppression elements into a single mechanical system. The height of the train AC is assumed to be at the same level as the centre of mass of the train (Wei et al. 2014). The authors’ modelled train in the UM package environment consists of a two-section locomotive with a mass of 250 t and 88 freight wagons. The mass of each wagon is 90 t. The total weight of the train is 8170 t, the length of the train – 1330 m. Locomotives and wagons joined by AC.
Fig. 1 Forces acting on the rail vehicle: $F_{Gli}$ is the force exerted on automatic couplings, N; $X_i$ is the vehicle displacement, m; $v_i$ is the running speed, m/s; $W_i$ is gravitation force (weight), N; $F_A$ is the air dynamic resistance, N; $F_B$ is the braking force, N; $F_C$ is the resistance of track curves, N; $F_W$ is the track slope resistance, N; $F_L$ is the wheel-set/rail contact resistance, N; $F_G$ is the traction force, N.

When braking the train in different modes, the brake pads are pressed with different forces. PBS and EPBS simulation is performed by examining the air flow from reservoirs to brake cylinders. When examining the geometry of typical pneumatic tubes, the flow in the tubes is considered to be unidirectional, i.e. moving along the main axis of the tube.

The amount of heat transmitted, friction in the pipeline, due to the diameter of the pipes and the variation of entropy, is simulated according to the equations (1), (2), (3) and (4) that are based on the preservation of energy and acceleration [11]:

$$\frac{\partial p}{\partial t} + \rho \frac{\partial u}{\partial x} + \frac{\partial u}{\partial x} + \frac{\rho u df}{F} \frac{du}{dx} = 0 ; \quad (1)$$

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + \frac{\partial p}{\partial x} + G = 0 ; \quad (2)$$

$$\left(\frac{\partial p}{\partial t} + u \frac{\partial p}{\partial x}\right) - a^2 \left(\frac{\partial p}{\partial t} + u \frac{\partial u}{\partial x}\right) - (k-1) \rho (q + uG) = 0 ; \quad (3)$$

$$G = \frac{u^2}{2} ; \quad (4)$$

where $\rho$ is air pressure; $a$ is air speed; $D$ is the diameter of the pneumatic pipeline; $f$ is a coefficient of friction; $F$ is the cross-sectional area of the pipe; $k$ is heat exchange coefficient; $q$ is heat transfer rate; $t$ is time; $u$ is compressed air speed; $x$ is the distance; $\rho$ is the density of compressed air, $G$ is the amount of heat.

Longitudinal train dynamics is defined as the longitudinal movement of the rail vehicle in the longitudinal direction. This includes the longitudinal movement of the train as an entire mechanical system and the longitudinal relative movements resulting from the elasticity and gaps of the mechanical connections on the train vehicle, including the AC interaction.

The longitudinal dynamic behaviour of the train is mathematically described by a differential system of equations. When developing longitudinal dynamic equations (models), it is assumed that the movement of rail cars is only in the longitudinal running direction, i.e. the transverse and vertical variations of the train vehicle are ignored. For differential equations, a simplified train model is used (see Fig. 2).

Fig. 2 Three-mass train model: $a$ is train acceleration, m/s$^2$; $c$ is the suppression constant, Ns/m; $k$ is stiffness constant, N/m; $m$ is mass, kg; $v$ is the speed of the train, m/s; $x$ is vehicle displacement, m; $F_g$ is gravity force due to the rail category, N; $F_r$ is the sum of motion resistances, N; $F_{cub}$ is locomotive traction and train braking forces, N.
As can be seen from Fig. 2, only the forces acting in the running direction of the train, i.e., along the rail track axis X, are evaluated in the presented model of the longitudinal dynamics of the heavy train.

3. Results of the Simulation of the Braking Process of a Long and Heavy Train on a Track Slope with a Curve

In the numerical simulation of the long train, the initial running speed of 20 m/s (60 km/h) is selected. The emergency braking of the locomotive starts after the locomotive has been running 2530 m from the starting point. At this point, the entire train is already running on 2800 m long (6-10) %o track slope with a curve of 400 m radius. While the train runs into the curve, the forces exerted on the AC of the locomotive raise to the highest values. The following parameters are monitored during numerical simulation:

a) the longitudinal force exerted on the AC of the entire train during braking by PBS and EPBS on a track slope with a curve (see Fig. 3 and Fig. 4);

b) the maximum longitudinal force exerted to the AC during braking by PBS and EPBS on a track slope with a curve (see Fig. 5 and Fig. 6).

When the train is running in idle mode on a horizontal track, the train inevitably decelerates due to running resistance. As a result, longitudinal compressive forces of up to 200 kN are generated in AC. When the train starts running on a track slope, the acceleration of the train on the slope causes the tensile forces to act on the AC. When the train enters the track curve, the compressive forces start acting on the AC again. The complete processes of variation of longitudinal forces with additional braking forces on the train are shown in Fig. 3 (case EBS) and in Fig. 4 (case EPBS).

![Fig. 3 The longitudinal force acting on the automatic couplings of the entire train when braking by PBS on a slope with a curve](image3)

![Fig. 4 Longitudinal force acting on the automatic couplings of the entire train when braking by EPBS on a slope with a curve](image4)

For more detailed analysis, the diagrams of the longitudinal force raised on the most loaded AC of the 35th car are shown in Fig. 5 (case EBS) and the 86th car in Fig. 6 (case EPBS).

Figs. 3-6 diagrams show that the maximum compressive force acting on the car 35th during braking is 486 kN (in PBS case) and on the 86th car 302 kN (in EPBS case). It should be noted that the longitudinal force does not exceed the permissible limit of 932 kN indicated in the technical specifications of RZHD (2010). During the simulation the braking parameters of the long and heavy train \( \nu_p = 20 \text{ m/s} \) with different braking systems (PBS and EPBS) were analysed. All results of numerical simulation of the train dynamical behaviour during the braking by EPBS and PBS are presented in Table 1.
Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type of brakes</th>
<th>For forces acting on automatic clutches, kN</th>
<th>Braking time, s</th>
<th>Stopping distance, m</th>
<th>Brake actuation delay, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric-pneumatic brakes (EPB)</td>
<td>302</td>
<td>50.1</td>
<td>631</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Pneumatic brakes (PB)</td>
<td>486</td>
<td>51.7</td>
<td>689</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Difference:</td>
<td>183</td>
<td>1.6</td>
<td>58</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

The braking distance of the train during EP braking on a track slope with a curve is shorter by 58 metres (Table 1), i.e., when braking by EPBS, the stopping distance is 631 m and 689 m/s when braking with the PBS. The dynamic stability of the long train braked by EPBS is also significantly improved, as the longitudinal forces acting on the AC are reduced by as much as 186 kN or 38%.

The Authors intend to further investigate the braking processes of long and heavy trains and the dynamic stability of the train vehicle by changing the position of two locomotives in the train according to 3 schemes (manners): both locomotives at the front of the train; the first locomotive at the front of the train, the second one in the middle of the train; the first locomotive in the middle of the train, the second one at the end of the train. The aim is to investigate possible changes in the longitudinal dynamics of long heavy trains and the stability of the train vehicle during braking on different railway line sectors/sections of various track profiles.

4. Conclusions

1. Numerical simulation of long train longitudinal dynamics shows that the forces exerted on automatic couplings do not exceed the permissible values of long and heavy freight trains during braking on the track slopes with curves.

2. When braking the heavy train on a track slope with a curve with the electric-pneumatic braking system, the braking time is reduced by 1.6 s compared to the pneumatic braking system, the stopping distance is smaller by 58 m, and the maximum longitudinal force acting on the automatic couplings is reduced as much as 183 kN (38%).
3. When launching a long and heavy train on the line, it is not necessary to change the arrangement of the signalling and automatic signals (warning the intervals), as the braking distance of long and heavy trains is only 8.6% longer than of a conventional freight train. This can be offset by traffic scheduling these trains.

4. Further investigations on braking processes of long and heavy trains are envisaged by changing the location of the two locomotives on the long train, on which the actuation of the braking time and the continuity of the longitudinal forces exerted on the automatic couplings of the train should significantly depend.

References

Application of Software Complexes for Monitoring of Cellular Networks of Mobile Communication KPI on Railway Transport

V. Popov¹, V. Skudnov², A. Shevchenko³, A. Vasiljevs⁴

¹Riga Technical University, Azenes street 12a, LV-1048, Riga, Latvia, E-mail: popovs@latnet.lv
²Riga Technical University, Azenes street 12a, LV-1048, Riga, Latvia, E-mail: vladimir.skudnov@sotus.net
³Riga Technical University, Azenes street 12a, LV-1048, Riga, Latvia, E-mail: alexey@cryptolab.net
⁴Riga Technical University, Azenes street 12a, LV-1048, Riga, Latvia, E-mail: aleksejs@vasiljevs.id.lv

Abstract

In order to reliably ensure the high quality of cellular mobile services provided by the operator, it is necessary to constantly measure and monitor various parameters of cellular networks in accordance with the standards: ETSI TS 102250-2. Monitoring the state of the cellular networks of mobile communication (CNMC) allows to identify problem areas in time, as well as to eliminate possible problems before they occur, while neglecting of the CNMC monitoring sometimes leads to disastrous consequences, up to the network section goes out of service, which is extremely important to ensure the reliability of the systems of automation, telemechanic and data transmission for railway vehicles. This work considers the problems of evaluating the most representative KPIs for CNMC, by using modern software complexes to measure and monitor KPIs in 2G (GSM-R), 3G, 4G, Wi-Fi networks. Since in recent years, smartphones have started to operate with multiple active SIM card slots with Dual Sim Full Active (DSFA) technology, which is small, low cost and have a set of installed programs, such smartphones can be used to easily and efficiently monitor CNMC of multiple operators. At the same time, if GSM-R is the main operator, then other CNMC operators create electromagnetic interference and it is possible to evaluate the electromagnetic compatibility (EMC) in the operation of all CNMC. This work presents modeling experimental results obtained by using software complexes for monitoring KPI of 2G (GSM-R), 3G, 4G, Wi-Fi networks on the Latvian Railway.

KEY WORDS: measurements, monitoring, cellular networks of mobile communication (CNMC), key performance indicator (KPI), software complex (SC), android, railway

1. Introduction

The technological radio communication networks (train, station, maintenance and operational) cover the entire network of European railways and are operated primarily using specialized digital radio equipment. The active development of radio communication services, including cellular networks of mobile communication (CNMC), requires the improvement of radio frequency resource management methods. As is known, radio monitoring is one of the most important functions of the radio frequency resource management system. The methods of radio monitoring are continuously improved following the development of its facilities, which include the aggregate electromagnetic environment, including a load of radio frequency bands, numerous active radio electronic means, high-frequency industrial, medical and scientific installations, sources of industrial and natural interference. Radio frequency resource management and radio monitoring should be closely linked and ultimately determine both the optimization of such networks and the electromagnetic compatibility of the radio systems used. To consider only CNMC, e.g. GSM-R cellular network, it is necessary to continuously measure and monitor various CNMC parameters in accordance with European standards and the standards adopted in the respective country in order to ensure high quality of such cellular network services provided by the railway operator. Tracking of the CNMC condition allows identifying problem areas in time, as well as eliminating possible violations before they occur, while neglecting the CNMC monitoring can lead to disastrous consequences, up to the exit of the network section from the operational condition, which is simply not acceptable for the railway transport network.

2. Measuring and Monitoring Equipment and Software Complexes

For measurements and monitoring of CNMC now the firms specializing in the creation and manufacture of measuring and monitoring equipment let out the whole line of measuring complexes. For example, such firms can be referred to: Rohde & Schwartz - CMW500/CMX500, InVista - TEMS, Huawei - GENEX and others. Measuring suites offered by them are capable to conduct measurements both for 2G, 3G and 4G generations, and at the same time to provide a rather objective assessment of network service quality. However, each measuring complex, naturally, has its own features. For example, a specific feature of the specified measuring complexes is the obligatory presence of the qualified operators at a control panel. The exception is the complex TEMS Automatic, which collects data from the subscriber’s terminal without the user's knowledge, but there are also restrictions, for example, when testing an active...
connection the funds from the subscriber's account are spent. Besides, to test a certain sector, a subscriber must be in this sector. Considering briefly the requirements for the testing complexes for measuring and monitoring of CNMC: the list of frequencies allowed for the given company (operator); parameters of the cellular communication network (status of the mobile station and base station); radio signal parameters; parameters of the level of quality of speech transmission in the communication channel; parameters of binding of the complex location to the digital map; statistics of connections; parameters of the channel change (handover); parameters of the neighboring cells; parameters of the data transmission service GPRS, and so on. In addition, it is necessary to monitor for the implementation of monitoring: 1) the power level of the base station and mobile station transmitters; 2) signal levels at the mobile station receiver input and at the base station receiver input (which are usually compared with the sensitivity of the respective devices); 3) signal/interference ratio level (C/I - Carrier to Interference); 4) transmission quality level of frames; 5) distance from the base station to the mobile station; 6) signal power level of neighboring base stations, taking into account the permitted radio frequencies (Color Code); 7) synchronization correction mechanism performance; digital and mobile station transmission speed. After the end of the tests, the measuring complex should issue temporary diagrams of CNMC parameters changes and only after their analysis should the conclusion about the level of service of cellular communication networks in a given network section be made. Due to the growing popularity of mobile devices operating on the basis of the Android operating system (OS), nowadays there are many programs for monitoring 2G (GSM-R)/3G/4G networks [1-16]: TEMS Pocket, Cell Mapper, G-MoN, NetTrack Lite, GSM Monitor, G-NetTrack Pro, Antenna, Network Signal Strength, GSM Monitor, GSM Signal Monitor, Cell Phone Coverage Map, Location Finder and GSM mapper, GSM Signal Monitoring, OpenSignal, Net monitor, GSM Signal Monitor & SIM Card Info, Network Cell Info Lite & Wi-Fi Signal and others, and 9 programs for measuring and monitoring WiFi networks [15]. With the help of these software complexes in the online mode, measurements and monitoring of the values of CNMC parameters from a large set of KPIs are implemented more easily and accessible, for example, such as: a list of used radio frequencies, radio signal levels, type CNMC, the presence of 3G or 4G, digital maps showing not only the location of base stations, but also the distance between them, etc.

3. Experimental Modeling Results Obtained Using Software Complexes for Measuring and Monitoring 2G (GSM-R), 3G, 4G, WiFi Networks on the Latvian Railway

The following modeling experiments were carried out to evaluate the possibilities of using the above mentioned software complexes in practice for monitoring CNMC parameters using tablet/laptop/smartphone powered by Android 7.1 operation system:

1. Monitoring of BTS-MS radiofrequencies, showed in Fig. 1: Using the CellMapper and Network Cell Info Lite software complexes, the radiofrequencies in the downlink and uplink modes were determined, while for LTE in the Network Cell Info Lite -EARFCN stands for E-UTRA Absolute Radio Frequency Channel Number (EARFCN number)

![Fig. 1 Monitoring of radio frequencies BTS-MS](a) (CellMapper; b) (Network Cell; c) (TEMS Pocket)
\[ F_{\text{downlink}} = \text{FDLLow} + 0.1 \times (\text{NDL} - \text{NDLOffset}) \times F_{\text{downlink}} = \text{FDLLow} + 0.1 \times (\text{NDL} - \text{NDLOffset}); \]  

\[ F_{\text{uplink}} = \text{FULLow} + 0.1 \times (\text{NUL} - \text{NULOffset}) \times F_{\text{uplink}} = \text{FULLow} + 0.1 \times (\text{NUL} - \text{NULOffset}), \]

where \( \text{NDL} = \) downlink EARFCN; \( \text{NUL} = \) uplink EARFCN; \( \text{NDLOffset} = \) offset used to calculate downlink EARFCN; \( \text{NULoffset} = \) offset used to calculate uplink EARFCN.

2. Monitoring of topology and radio covering CNMC: As an example, Fig. 2 shows data on monitoring the CNMC topology, the location of the BTS, and the change in radio signal levels along the path.

![Fig. 2 Monitoring of linear network CNMC for railway track - Torņakalns–Tukums [SC- a – Network Cell Info; b – G-Net Track Lite; c – BITE operator]](image)

As follows from crowd-sourced coverage maps, a color change characterizes the measured levels of BTS radio signals along a railroad track.

3. Monitoring of radio signals power BTS and MS: In almost all of the SCs listed, the first part implements monitoring of radio signal levels (dBm). Fig. 3 shows data on monitoring the power levels of radio signals along two paths: Torņakalns – Tukums using SC - Network Cell Info and Network Cell Info Lite.

![Fig. 3 Monitoring of power radio signals CNMC for railway track - Torņakalns–Tukums [SC- a – Network Cell Info; b – Network Cell Info Lite; c – RSRP in Net Cell Info Lite]](image)

Fig. 4. shows the results of monitoring RSRP levels along the Jelgava-Riga railway using SC-Network Cell Info Lite, while the measurements were carried out in a moving train (RSRP levels are indicated by color values, where RSRP < -95 dBm is green, yellow RSRP from -99 to -108 dBm and orange RSRP from > -108 dBm to - 118 dBm).

Fig. 5, a, b shows monitoring of the main parameters RSSI, RSRQ, RSRP, changing over time, the movement of the composition, while the relationship between these parameters are determined by the following formulas:

\[ \text{RSSI} = \text{RSRP} + 10 \log(12N); \]  

\[ \text{RSRQ (dB)} = 10\log (N) + \text{RSRP (dBm)} - \text{RSSI (dBm)}, \]

where \( N \) is a variable that depends on the load, interference and channel bandwidth of the mobile cellular network, and the value of \( N \) depends of the device (table/laptop) movement time in the composition. It should be noted that with RSRQ > (-9 dB) - signal quality - excellent, with RSRQ - (-9 dB) to (-12dB) - signal quality – good, excellent, with
RSRQ < (-13 dB) - signal quality - fair to poor.

As follows from Fig. 4, Fig. 5 signal quality on the main route of the composition exceeded the value (-13 dB), which indicates stable radio communication in the cellular network. However, in certain areas where the railway surrounded by forest vegetation, as well as at the edges of the CNMC cells, the RSRQ value fell to fair to poor.

4. Conclusions

The work considered software complexes for monitoring CNMC of three generations and, on their basis, obtained experimental KPI values when monitoring CNMC on the Latvian railway. All these software complexes, to one degree or another, have different and similar functions, while, as practice has shown, it is best to use several at once. The main advantages of the software complexes based on Android OS are: 1) when monitoring is implemented, it is possible to display KPIs and their changes in dynamics and compile a radio coverage map with signal level data;
2) the use of software complexes - Network Cell Info Lite - Mobile & WiFi Signal [17] allows simultaneous monitoring by CNMC (of a specific operator) and Wi-Fi network, which is important while waiting for railway vehicles. The main drawback of almost all software complexes is the implementation of monitoring only in the CNMC of one operator, to which the monitoring device itself (Android) is connected with which measurements are made. Therefore, if tablet/laptop/smartphone has a SIM card of the TELE2 operator, then monitoring will be implemented for CNMC Tele2, but BITE and LMT CNMC cannot be monitored at the same time. However, this drawback can be eliminated either by using several devices working on the software complexes of the respective operators, and then implementing the KPI comparison of the studied CNMC for the same tested area or by using an Dual Sim Full Active (DSFA) technology-enabled device (smartphone/tablet), in this case CNMC can be monitored effectively at the same time for multiple operators. As mentioned above, in recent years smartphones have started to operate with multiple active SIM card slots with Dual Sim Full Active (DSFA) technology, which are small, low cost and have a set of installed programs, such smartphones can be used to easily and efficiently monitor CNMC of multiple operators. At the same time, if GSM-R is the main operator, then other CNMC operators create electromagnetic interference and it becomes possible to evaluate the electromagnetic compatibility (EMC) in the operation of all CNMC.

It should be noted that, depending on the monitoring tasks, the software complexes can be quite useful both in railway transport and in universities, when training students in the discipline "Mobile Communication Systems in Railway Transport" and advanced training of railway transport employees.

References

1. ETSI TS 102 250-2 V2.6.1. (2017-10) – ITU.
14. 10 GSM/3G/4G monitoring programs for Android. Available from: https://bloganten.ru/10-pro gramm-monitoringa-gsm3g4g-dlya-android/
16. GSM Signal Monitor & SIM Card Info.
17. Network Cell Info Lite - Mobile & WiFi Signal.
Methods of Ships' External Steering in Condition of Close Quarters Situation

I. Burmaka¹, M. Kulakov², Y. Khussein³, O. Yanchetskyy⁴

¹National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: burmaka1964@gmail.com
²National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: endeavorlxze1@gmail.com
³National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: nav.dep@mail.ru
⁴National University “Odessa Maritime Academy”, Didrikhson str. 8, 65029, Odessa, Ukraine, E-mail: nav.dep@mail.ru

Abstract

In this article the main advantages of external ships’ steering principle in close quarters situation has been considered. It has been shown that its main methods comprise applying course alteration manoeuvre for both vessels, their speed alteration manoeuvre and course alteration manoeuvre of one vessel and speed alteration manoeuvre of another vessel. The realization of the mentioned methods has been suggested using computer modelling and numerical parameters have been listed.

KEY WORDS: the safety of navigation, prevention of collisions by ships, external steering of ships in the passing process, assessment of close quarters situation, ship’s movement infeasible region parameters

1. Introduction

The provision of safe passing of vessels in close quarters situation in course of navigation within congested waters is one of the most pressing issues of safety of navigation. In this respect Vessel Traffic Services (VTS) are established in congested navigable areas with high traffic density in order to monitor the process of navigation and handle the movement of vessels in close quarters situation, moreover, VTS stations must be equipped with advanced means for collision prevention using methods of safe passing for two or more ships. Consequently, studying issues connected with the steering of ships in close quarters situation within the VTS control area covered in the present article is considered to be an actual and promising avenue.

In papers [1-6] various models of ships’ interaction formalization in course of passing and safe manoeuvre calculation procedure have been suggested. In paper [1] methods of the theory of optimal discrete processes have been used to describe safe manoeuvre and in paper [2] it has been suggested to apply the method of nonlinear integral invariances. Formalization of ships’ interaction in course of passing as a part of differential game theory has been performed in papers [3, 4].

In paper [5] the issue of collision prevention by ships has been profoundly and integrally studied and method of flexible strategies of their passing has been suggested which in its turn allows forming the optimal strategy of passing with several dangerous targets taking into account requirements which must be met according to COLREGs-72, navigational hazards and ship’s inertia braking characteristics. Paper [6] highlights the generalization of ships’ interaction concept with the risk of a collision where in formalization of the COLREGs-72 has been suggested.

The objective of the passing of ships at sea has been emphasized in monograph [7], wherein the method of collision prevention by means of taking a parallel track has been introduced. In paper [8] steering of three ships safe passing has been considered and the results of research efficiency of pair passing manoeuvres have been shown in paper [9].

In considered papers the strategies of ship’s passing are performed by means of the local independent principle of handling of the passing process which precedes the interaction between ships in the condition of close quarters situation which defines their mutual behaviour within the passing process. In case of close quarters situation it is suggested to perform formalization of the interaction of ships by means of a differential game or binary coordination which has been implemented in COLREGs-72 in a part that regulates manoeuvring of ships in close quarters situation. However, in the course of handling the process of passing by VTS the necessity of mutual agreement on manoeuvres by ships with interaction becomes unnecessary, i.e the principle of external handling of passing is implemented, the peculiarities of which are highlighted in this article.

The objective of the given article is an analysis of collision prevention methods by external steering of ships in process of their passing.

2. Presentation

In course of the external steering of the passing process an independent operator monitors the situation of
approaching a pair of ships and in case of the risk of collision forms a general strategy of passing by both ships, preventing their collision. Such steering may be performed by VTS as well as by automatic identification system with the same capabilities and installed on every ship which can carry out a task on passing in multi-ship encounter situation and implements obtained individual strategy. The advantage of total handling of passing process by an external person is the same interpretation of close quarters situation in the selection of the passing manoeuvres. As in process of external steering, in case if close quarters situations exists, the selection of strategy is not performed by approaching ships the coordination system which regulates the interaction of ships approaching on a collision course is absent (COLREGs-72).

Paper [10] shows that it is reasonable to illustrate the multitude of conditions of a pair of vessels approaching a collision course by region $Q_k$, which is reflected on the enlarged plane of ships’ courses as is shown in Fig. 1.

Borders of the region are coordinates of ships’ courses $(K_1, K_2)$, satisfying equation:

$$\sin(K_2 - \theta) = \frac{V_1}{V_2} \sin(M_i - \theta),$$

(1)

where $\theta = \alpha \pm \arcsin \frac{D_0}{D}$; $\alpha$ and $D$ – bearing and distance between ships accordingly; $D_0$ – the maximum permitted distance of approaching.

With determining coordinate $(K_1, K_2)$ inside the region of collision courses $Q_k$ the closest point of approach $D_{\text{min}}$ is smaller than the maximum permitted distance $D_0$, and approaching of ships is dangerous. The risk of collision is absent if coordinate $(K_1, K_2)$ is in the border or out of region $Q_k$. In case when for pair of ships coordinate with program courses $(K_{1o}, K_{2o})$ is in region $Q_k$, it is necessary to alter courses to values $K_{1y}$ and $K_{2y}$ in presence of unaltered speeds of ships, wherein coordinate $(K_{1y}, K_{2y})$ does not belong to collision courses and is located in its border. Change from coordinate $(K_{1o}, K_{2o})$ of region $Q_k$ to coordinate $(K_{1y}, K_{2y})$, must comply with minimum alteration of ships’ courses.

In case when ships, which are approaching on a collision course, cannot alter their course, a collision can be avoided by alteration of their speeds. In this case multitude of conditions of an approaching pair of ships should be represented graphically by region of dangerous speeds $Q_v$, which is similar to the region of dangerous courses $Q_k$, with the only difference, wherein each coordinate $(V_1, V_2)$ of pair speeds of ships comply with the closest point of approach between ships $D_{\text{min}}$. The border of the dangerous region of speeds each coordinate of which corresponds to the closest point of approach which is in its turn equal to maximum permitted distance, i.e. $D_{\text{min}} = D_0$, is formed by expressions [11]:

$$V_{1y} = V_2 \frac{\sin(K_2 - \theta)}{\sin(K_1 - \theta)}, V_{2y} = V_1 \frac{\sin(K_1 - \theta)}{\sin(K_2 - \theta)},$$

(2)
where \( \theta' = \alpha - \arcsin \frac{D_2}{D}, \ \theta = \alpha + \arcsin \frac{D_2}{D} \).

With constant values of ships’ courses \( K_1 \) and \( K_2 \) the borders of the dangerous region of speeds are linear as is shown in Fig. 2.

Region of dangerous speeds of ships \( Q \), allows us to assess the risk of their approaching and select speeds that ensure safe passing. As it follows from Fig. 2 with initial speeds of ships \( V_1 = 18 \) knots and \( V_2 = 19 \) knots coordinate \( (V_1, V_2) \in Q \) and approaching of ships is dangerous, to pass safely it is necessary to select coordinate \( (V_1, V_2) \) in the border of region \( Q \), i.e. to reduce the speeds of ships to values \( V'_1 = 16 \) knots and \( V'_2 = 11,5 \) knots.

However, the possibility of safe passing of ships increases with the application of another type of passing wherein the ship alters course \( K_1 \), keeping speed unaltered \( V'_1 \), and another one keeping her course \( K_2 \) in her turn reduces speed \( V'_2 \).

In the case indicated above it is necessary to consider the region of dangerous courses of one vessel and speeds of another where in the combination with which closest point of approach becomes smaller than the maximum permitted distance, i.e. approaching of ships is dangerous.

There are two borders of region \( \Omega_{K1,j} \), in which equality is reached \( \min D = D_j \). In paper [12] analytical expressions for borders of the region \( \Omega_{K1,j} \) are given:

\[
V^{(1)}_2 = \frac{\sin (K_1 - \gamma(1))}{\mu(1)} = \frac{V_1}{\sin \left[ K_2 - \left( \alpha + \arcsin \frac{D_2}{D} \right) \right]} \sin \left[ K_1 - \left( \alpha - \arcsin \frac{D_2}{D} \right) \right] ,
\]

\[
V^{(2)}_2 = \frac{\sin (K_1 - \gamma(2))}{\mu(2)} = \frac{V_1}{\sin \left[ K_2 - \left( \alpha - \arcsin \frac{D_2}{D} \right) \right]} \sin \left[ K_1 - \left( \alpha + \arcsin \frac{D_2}{D} \right) \right] ,
\]

where \( \gamma^{(1,2)} = \alpha \mu \arcsin \left( \frac{D_2}{D} \right) \); \( \mu^{(1,2)} = \frac{\sin \left( K_2 - \gamma^{(1,2)} \right)}{V_1} \).

In course of calculation of speed \( V_2 \), reducing of the speed of the second ship to value \( V'_2 \) is expected, and then proceeding at this speed up to time to reach the closest point of approach after which the second ship increases her speed to the initial value.

Fig. 3 illustrates region \( \Omega_{K1,j} \) for the close quarter’s situation considered above, wherein reducing of the speed of the second ship has been carried out by means of active braking. Results of checking of correctness of region borders have been presented \( \Omega_{K1,j} \) – coordinate of the border with parameters \( K_1 = 163^\circ \) has been selected and \( V_2 = 15,6 \) knots, for which value \( \min D = 1,01 \) miles has been obtained.
3. Conclusions

1. The principle of external steering of the ship in the process of passing has been considered and it has been shown that the main advantage is a similar interpretation of close quarters situation in course of selection of passing manoeuvre and the absence of the coordination system which regulates the interaction of ships approaching on a collision course.

2. Main methods of close quarters situation evaluation and selection of their passing manoeuvres in case of need have been given. It has been shown that the main methods of external steering of ships' passing process are the region of dangerous courses of approaching ships, the region of their dangerous speeds and region of dangerous courses of one ship and speeds of another one, wherein analytical expressions of their borders have been given.

3. The rationale of application of considered methods through automatic identification system in course of external steering of ships in the process of passing has been shown.

References

Systematic Efficiency of Global Merchant Shipping Power Safety

M. Kolegaiev$^1$, N. Primachov$^2$, I. Kolegayev$^3$

$^1$National University “Odessa Maritime Academy”, Didrikhson 13, building 3, 65029, Odessa, Ukraine, E-mail: smf@onma.edu.ua
$^2$Head of Economic Theory and Business Undertakings on Maritime Transport department, Didrikhson 13, building 3, 65029, Odessa, Ukraine, E-mail: smf@onma.edu.ua
$^3$National University “Odessa Maritime Academy”, Didrikhson 13, building 3, 65029, Odessa, Ukraine, E-mail: smf@onma.edu.ua

Abstract

The article analyzes the factors affecting the energy security of merchant shipping. The main factors identified are: the demand for the deadweight of the transport fleet, cargo transportation routes and delivery time, and the environmental consequences of transportation. Criteria are identified that determine the functional efficiency of shipping companies - compliance with the economic and environmental standards of international maritime organizations, the level of innovation. The selected criteria determine the choice of technical solutions in the design and modernization of merchant ships. A mathematical model is proposed for predicting the energy security of a shipping company, taking into account economic and environmental factors.

KEY WORDS: energy security of the merchant fleet, modeling of energy security, environmental technologies for maritime transport, environmental damage from maritime transport

1. Introduction

The modern level of global economic development on the whole and the state of separate basic sectors of international economic relations are characterized by the variety of approaches to the achievement of system parameters stability in general. It is necessary to consider one such approach to be the increase of system safety role of functional activity of separate production-economical subsystems. In this case, this process is examined by the example of role differentiation and concept expansion of merchant shipping safe development.

Meanwhile, marine transport role expansion in the system of international economic relations stipulates the necessity of basic constituents clarification of merchant ship ping safe development concept. Therefore the systematic safety concept has been introduced. It includes providing steady functioning of all constituents of the world economy in accordance with the corresponding criteria: preserving of natural balance and stable economic and technical condition of shipping companies, commercial ports on the basis of indexes.

The loss of Ukraine marine transport constituent is examined as an example over the country’s newest history period. Ukraine’s foreign trade goods traffic is 90 percent based on chartering foreign tonnage that leads to currency profit yield loss. Because of the limited nature of investment resources, Ukrainian shipowners’ fleet is either in a grey or blacklist. Freight terminals fall short of modern requirements on productivity and safety. The country has lost the priority of effective transit structure of international economic relations.

In the control system of the marine transport safety system, it is necessary to distinguish the role of marine transport policy, the regulatory constituent of global institutes, technical and economical level of ships and corresponding management and fleet and ports work organization in the system of intermodal transport technologies.

2. External Efficiency of Marine Transport Industry Subsystems Functioning

Subsystems activity of marine transport industry operating activity as a business structure variety is aimed at maximization of enterprise efficiency on the basis of profitability growth. It predetermines the choice of investment activity strategy, innovative technologies use and manager’s priorities [5]. At the same time, functional activity parameters of the marine transport industry separate subsystems (merchant marine, ports) form the considerable non-systematic effects of goods owners. It is stipulated by creating conditions for quality, timely and economical delivery of commodity mass to consumers. At the same time, national industrial infrastructure is aimed at the achievement of transport safety of residents positioning in segments of the international division of labour.

It is the provision of cargo traffics stability with merchant marine conditioned by global trade relations that forms the external effect of a marine transport industry performance [6]. In turn, this result predetermines shipowners enterprise efficiency parameters. For keeping or maximizing the enterprise effect the choice of such types of vessels, which meet modern innovative approaches and conventional standards and rules in accordance with their technical and economical level, is becoming important.

External (non-transportation) transport fleet work efficiency is formed due to innovative technologies of goods...
owners’ service and rational attitude towards the environment. Goods owners get the opportunity to use turnover means rationally and decrease the need in credit resources thanks to it. Society saves considerable resources for subsequent elimination of negative consequences at vessels’ negative influence on air and water space decrease.

In the long run, the development and marine transport work are stipulated by external in relation to shipowners’ structures factors. The foreign trade volume and pattern, which predetermine transport fleet deadweight demand, are becoming the main ones. Thus the cargo transportation routes and delivery time limitation predetermine the value of choice of the vessels technical and economical level from the point of view of goods producers’ preferences [7]. This condition forms shipowners’ companies’ tasks as for optimization of capital and current costs for building and using of ships. For this reason routing variants of ‘One belt is one way’ known initiative is formed.

It is the size of a non-transportation effect that stipulates shipowners’ competitive positions at the seaborne trade market. It confirms the stability of leading world marine transporting brands positioning.

3. Systematic Efficiency of Fleet Operator Activity Safety

In spite of the initial signs of a marine transport industry for the steady balanced development of global economic relations, the situation of a marine transport complex negative influence strengthening on the environment pollution has been formed. Along with other types of industries that use different types of fuel, marine transport predetermines the balance of nature risk. Therefore the necessity of comparison of economic efficiency of functional fleet activity with its negative influence on the environment appears.

It is the comparison of these vitally important positive and negative influences of marine transport subsystems on the economy and natural condition that predetermines necessary economically reasonable technical solutions [8].

In the given statement of the problem, forming and keeping of external economic relations normalized results are considered under the marine transport industry development systematic safety. Preservation of quantitative and quality characteristics of economic resources of global marine transport industry corresponding systems that provides seaborne trade global market stability becomes fundamental.

It is achieved by the corresponding level of vessels and port terminals’ technical and economical indexes while having necessary requirements for all levels of management competence. At the same time, systematic safety in the seaborne trade market structure is provided by the corresponding reaction to the occurrence of economic and technical sorts of risks and neutralization of the development of different forms of external negative externalities.

Balance of keeping of world merchant marine deadweight is distinguished in relation to the size of goods traffics in the structure of achievement of systematic economic security of foreign trade relations. But it is necessary to keep in mind that for separate shipowners structures under the general balance of demand and supply at the seaborne trade market, the risk of disparity of vessel characteristics to technical and economical limitations is kept. Thus, a certain surplus of tonnage is formed that stipulates the uneffectiveness risk of global shipping market separate subsystems functioning.

Finally, the achievement of marine transport safe functional activity systematic efficiency is conditioned by the next tasks solution:

- achievement of complete accordance of fleet transportability to the demands and amount of shipping;
- forming of normalized enterprise and macroeconomic indexes by shipping companies;
- necessary satisfaction to MLC Convention requirements of seaborne trade market corresponding operators’ transport vessels;
- requirements realization and limitations completeness to merchant marine vessels in accordance with environment protection standards;
- non-systematic risks decrease of operator merchant marine activity in the World Ocean water areas.

On the whole the merchant marine deadweight with the minimum risk of quantitative accordance to the world seaborne trade volume must be formed according to the following limitations:

\[
D_t = \frac{R_{wt}}{(1+i)} \frac{1}{m_d} (1 \pm x)(1 \pm y),
\]

where \(R_{wt}\) – is a world trade value, which is provided by the transport fleet of shipping companies; \(i\) – is development forecast rates of export-import operations; \(m_d\) – is a world trade value average cost falling on one ton of operating fleet deadweight; \(x\) – is expected changes in the trade volume structure causing the change of basic situation of seaborne trade market; \(y\) – is an estimation of innovative technologies influence character and limitations on negative externalities of fleet development in relation to the risks as for the environment; \(t\) – is a calculation period of forming of marine transport industry parameters.

\[
m_d = \frac{R_{wt}}{D_t},
\]

\(D_t\) – is a deadweight of the merchant marine, providing efficiency of external economic relations in the examined period.
These parameters provide stability of states’ participating in the world trade and necessary economic stability of shipowners’ structures at the demand and supply is balanced, which guarantees the accordance of average current expenses to the freight rates in the operator fleet activity segment.

4. Power Problems of Merchant Shipping Development

As it is known, modern merchant marine competition characteristic is based on maintenance innovative technological effectiveness of world trade goods traffic. The latter is predetermined by the structural features of the hull and power plant operation systematic safety. It is these positions that predetermine the vessel’s capital cost, and, consequently, the requirements to the income limit size. Besides, a special place in stability control system of separate shipping companies positioning is occupied by international regulators’ limitations, conventions and rules in relation to the ecological characteristics of a vessel power system.

As it is known, fuel expenses become a major condition, limiting the efficiency of shipowners’ structures entrepreneurial activity on the one hand and the other hand used fuel quality and parameters predetermine risks for the environment. Therefore the innovative development issue of marine power systems and the increase of energy supply use systematic safety become fundamental. Researches and developments are concentrated namely on this problem in many naval powers [9]. Estimation methods development significance of vessel operation efficiency rises in this aspect taking into account the cargo transportation net cost [10]. It is their functional activity in different marine regions that predetermines marine transport activity eventual effectiveness and risks for the environment.

Two problems of merchant shipping power efficiency have been formed. Firstly, from the position of shipowners’ structures, a fuel constituent in expenses is considerable that limits the level of vessel operation efficiency. Secondly, the limitation requirement for carbon dioxide emissions increases from the position of global ecological balance. It predetermines vessel price or a low sulphureous fuel price increase depending on engineering solutions.

The character of marine transport subsystems effectiveness formation is represented in Fig. 1. This character on the basis of the requirements for the systematic balanced development achievement reflects the change factors of the expenses and results whole set.

---

Fig. 1 Development efficiency and functional activity systematic limitations of the merchant marine

International economic relations parameters predetermine the tasks both of the mega economic balance and the
choice of technical and manager’s decisions from the position of the greatest enterprise efficiency of merchant marine operation.

As it is seen in picture 1, two limitations as for the choice of the shipping company adequate condition system at a seaborne trade global market are formed. On the one hand, effective positioning merchant shipping subsystems tasks, conditions and problems were formed. It is conditioned by economic, social and ecological aims of production development. Meanwhile, the systematic safety achievement principle is set in accordance with the problems’ current condition.

On the other hand, shipowners from the technical and economical possibilities position predetermine aims and tasks of systematic balance provision in marine transport economic conditions.

That is, normal economic indicators achievement in the external limitations structure in the conditions of the established seaborne trade global market [2] becomes the most intricate problem. And the technical and economical level of transport fleet vessels with the setting of power efficiency in accordance with the criteria of the economy and ecological safety occupies a major place in this process. It is these limitations that are taken into account by leading shipping companies.

However, the observance of decision balance is important. It provides business-projects stability and natural balance achievement.

Finally, as a result of difficult decisions that take into account the multidirectionality of economic, ecological and administrative aims, the perfection of mechanism and tools achievement of systematic efficiency of merchant shipping normalized power supply is needed. The operator’s income normal rate and the environment condition optimality are understood under the systematic efficiency of shipping company productive parameters formation, and, finally, under the transport services marine market.

5. Systematic Safety Results and Expenses Differentiation

Systematic safety of marine transport industry subsystems normalized condition forms the corresponding aggregate of results and expenses. The results should be divided into the formation levels. It is, first of all, mega economic, macroeconomic and enterprise indexes of economic and ecological balance [11, 12]. In addition, their content is important in accordance with objective functions: economic, ecological, technical and life safety.

The expenses are mainly formed through the owner’s capital resources activity. The efficiency estimation of the international administration system, the state support of enterprise structures and rationality of investment and operator’s activity of fleet and marine commercial ports is therefore important.

As it is known, enterprise structures are aimed at the rationality of investment and operator’s activity of fleet and marine commercial ports. However, the limitations demonstration of International marine organization standards and rules is increased in the marine transport industry system.

In these conditions merchant shipping power safety systematic effectiveness can be presented by the following algebraic expression

\[ E_{in} = Q_{mw} \left( n_{1} - n_{2} \right) p_{civ} - e_{r} K_{ae} + \left( r_{1} - r_{2} \right) P_{bs} - a_{as} Q_{w} \pm E_{in} \]  

where \( Q_{mw} \) is volumes of relative necessity decrease of fuel mineral types because of the optimization of vessels power output of a transport fleet as compared to standard conditions; \( n \) is energy supply consumption norms during current period (1) and as a result of innovative strategies realization (2); \( p_{civ} \) is fuel market value complying with the shipping systematic safety standards; \( e_{r} \) is capital assets enterprise efficiency standard; \( K_{ae} \) is transport facilities cost increase on non-systematic limitations in relation to business-standards; \( r \) is ecological damage parameters according to the variants of the marine transport industry condition during the base period (1) and as a result of innovative technologies realization (2); \( P_{bs} \) is a renewal cost of the subsequent balance in the ecology-production structure; \( a_{as} \) is current average expenses conditioned by renovaional technologies of relatively regulatory principles; \( Q_{w} \) is works volumes as for liquidation of marine transport activity negative consequences; \( E_{in} \) is other subsystems non-transportational effect as a result of innovative transport fleet characteristics increase.

Capital assets optimization priorities at effective activity directions, especially at the seaborne trade global market move from enterprise criteria to macro- and mega economical permissibility criteria. Therefore for any business structures oriented to the necessary volume of income formation, expenses as for the innovative direction subject to external limitations according to ecological compatibility and safety parameters are taken into consideration.

6. Conclusions

Thus, under conditions when the marine transport provides external economic relations efficiency at the world economy, the simultaneous solution of several technical, economical and ecological problems of global value is needed.

Finally, solution objectivity of a complex of socio-economical and ecological problems conditioned by the position of marine transport at the global economy predetermines the necessity of development system efficiency consideration of economic processes on the basis of involving of investment resources and specialists’ labour.

Expenses growth for marine transport enterprise structures economic potential formation with higher rates than financial indexes predetermines the necessity of stimulation mechanism and tools search of vessels further innovative
perfection on the whole and especially of power subsystems.

At the direct economic effect growth slowdown, the emergent effect increases and the synergy effect is formed. Therefore, on the EBITDA principle basis, it is necessary to choose the support form, foremost, shipowners while building vessels, the capital resources increase that mainly provides a non-transportation effect boost. Vessels normalized operation life cycle management remains fundamental guaranteeing investment resources return to the next stage beginning of economic potential renewal.

International Marine Organization current regulatory policy mainly examines general system results, investment and operating expenses in accordance with these standards lie on shipowners’ structures. But upon conditions complication their financial recourses of enterprise efficiency support are actually depleted. There appears a general support necessity of the most vulnerable fleet segments operating at the seaborne trade global market.

Thus one should have in mind that any scientifically set price characteristics from the position of business structures are substantially corrected by current market conditions and the accepted approach to the general system aims achievement.

References

Identification of Hazards Sources for the Use of Unmanned Aerial Vehicles (UAV) in Urban Airspace

A. Kobaszyńska-Twardowska, J. Łukasiewicz

1 Poznań University of Technology, Piotrowo 3, Poland, E-mail: anna.kobaszynska-twardowska@put.poznan.pl
2 Poznań University of Technology, Piotrowo 3, Poland, E-mail: jedrzej.lukasiewcz@put.poznan.pl

Abstract

Operating the unmanned aerial vehicles UAV is a popular hobby, also cultivated by people who do not have the appropriate permissions to fly. The airspace in Poland is divided into controlled and uncontrolled. In addition, the area airspace is divided into areas where UAV flights take place to require permits and approvals from relevant authorities. One should strive to ensure that actions taken with the use of UAVs are carried out with the lowest possible risk of threats. Both commercial and hobby ones. To be able to evaluate the risk of hazards, should be to identify sources hazard in the area. For this purpose, the article uses the possibilities of the Bow-Tie method. The area of analysis is characterized – the city of Poznań. The scope of the analysis was divided into a description of zones and the sources of threats were identified, on the basis of which the threats were formulated, and the risk reduction measures that should be applied to ensure the appropriate safety status were determined.

KEY WORDS: unmanned aerial vehicles, hazard sources, risk of hazard, division of airspace

1. Introduction - Airspace in Poland

According to the Aviation Law [7], airspace in Poland is divided into controlled and uncontrolled space. The controlled space extends from the flight level FL95 ceiling to the flight level FL 660. The uncontrolled space extends from ground level to the FL95 ceiling. The FL95 ceiling depends on atmospheric pressure and is calculated from the formula:

\[
\text{height} = \left[ \text{FL} + 30(\text{QNH} - 1013.25) \right] \times 0.3048, \quad (1)
\]

where QNH is an aeronautical code, indicating the atmospheric pressure adjusted to mean sea level; 1013.25 is the reference pressure on the sea surface resulting from the definition of the International Standard Atmosphere; 0.3048 is a conversion factor that allows you to express height in meters.

From formula (1) it follows that FL95 is an altitude, which depending on the QNH pressure is about 2850 meters.

In Poland according to International Civil Aviation Organization (ICAO) airspace is divided into three – dimensional segments, each of which is assigned to C, D or G class (Fig. 1). In class C or D all aircraft are subject to Air Traffic Control (ATC) clearance whereas in class G, ATC has no authority. ATC is a service provided by ground-based controllers who direct aircraft on the ground and through controlled airspace. In Poland all civil drone operations are lead in G class airspace most of them are leaders in airspace span from ground level to 150 meters above ground level.

In Poland according to International Civil Aviation Organization (ICAO) airspace is divided into three – dimensional segments, each of which is assigned to C, D or G class (Fig. 1). In class C or D all aircraft are subject to Air Traffic Control (ATC) clearance whereas in class G, ATC has no authority. ATC is a service provided by ground-based controllers who direct aircraft on the ground and through controlled airspace. In Poland all civil drone operations are lead in G class airspace most of them are leaders in airspace span from ground level to 150 meters above ground level.

Elements of the airspace structure in the agglomeration of Poznań (Fig. 2). Pursuant to the provisions of the Aviation Law Act, drone operations are allowed at any point in the airspace, if formal requirements are met. In the Poznań’s region, the Polish Air Navigation Services Agency has separated the following zones: CTR EPPO, ATZ EPPK, MCTR EPPW, MCTR EPKS, R and D. CTR is a control zone or controlled traffic region established in a volume of
airspace. CTR EPPO surrounds Poznań Airport Ławica. ATZ EPPK is an aerodrome traffic zone established for the protection of aerodrome traffic around an aerodrome. ATZ EPPK surrounds Poznan’s Aeroclub in the city of Kobylnica. MCTR EPKS is a military control zone that surrounds military airbase in the city of Krzesiny. MCTR EPPW is a military control zone which surrounds military airbase in city of Powidz. R is a restricted zone assigned to Greater Poland National Park and D is a dangerous zone assigned to the military training area in Biedrusko.

Fig. 2 Airspace elements in the agglomeration of Poznań [10]

The rules for performing unmanned aerial vehicle flights in the airspace in Poland were described in the announcement of the Regulation released by the Minister of Infrastructure on July 3, 2019, item 1497 [7]. In the case of Visual Line of Sight flights of a recreational or sporting nature, these rules are described in Annex 6 to this Regulation, in the case of flights of a non-recreational or sporting nature these rules are described in Annex 6a to this Regulation. According to these tasks, in the CTR zone, in the case of recreational or sport flights, or in the case of non-recreational or sport flights, the flights take place with the consent and on the terms specified by the manager of that zone. Such consent does not have to be given when operating unmanned aircraft up to 0.6 kg and up to a height of 30 meters from the ground at a distance of more than 1 km from the physical boundaries of the airport within the CTR. Permission to fly does not have to be granted also when flying with an aircraft up to 25 kg and up to a height of 100 meters from the ground at a distance of more than 6 km from the physical boundaries of the airport within the CTR (Fig. 3).

Fig. 3 Zones up to 1 km and up to 6 km from the airport borders

The rules for performing flights in the MCTR zone are described in [1]. According to these guidelines, VLOS flights can only take place with the consent and on the terms specified by the zone manager. According to these rules, the flight can take place at a distance of not less than 2 km from the physical boundaries of the airport and up to a height of 150 meters above ground level. Consent to the flight is obtained using the DroneRadar mobile application and by making a phone call to the airport TWR around which the zone is established. In the ATZ zone, regardless of the nature of the flight, the flights take place with the consent and on the terms specified by the manager of that zone. Such consent does not have to be given when operating unmanned aircraft up to 0.6 kg and up to a height of 30 meters from the ground at a distance of more than 1 km from the physical boundaries of the airport area. Permission to fly does not have to be granted also when flying with an unmanned aerial vehicle up to 25 kg and up to a height of 100 meters from the ground at a distance of more than 6 km from the physical boundaries of the airport area.

In zone R established to protect the resources of the Greater Poland National Park, flights can only take place with the consent of the park manager. In zone D protecting the military training area, flights may only take place with the consent of the training ground manager.

2. Bow-Tie Method

Unmanned aerial vehicles (UAV), commonly known as drones, are also increasingly popular in Poland. They are
present in the economy of our country in services such as infrastructure, agriculture, transport, security, media and entertainment, insurance and telecommunications [8]. As at 19/04/2018, a full 6,846 UAVO qualification certificates were issued (for UAV operators), of which 352 were issued to women and 6,494 to men (Table 1).

<table>
<thead>
<tr>
<th>Type of qualification certificate</th>
<th>License</th>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAVO Unmanned Aircraft Vehicle Operator</td>
<td>VLOS Visual Line of Sight</td>
<td>5</td>
<td>296</td>
<td>1560</td>
<td>1687</td>
<td>2103</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BVLOS Beyond Visual Line of Sight</td>
<td>2</td>
<td>53</td>
<td>152</td>
<td>172</td>
<td>492</td>
<td></td>
</tr>
<tr>
<td></td>
<td>INS Instructor</td>
<td>2</td>
<td>27</td>
<td>32</td>
<td>12</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

License:
1. VLOS - (Visual Line of Sight) operations in which an operator or observer of an unmanned aerial vehicle maintains direct eye contact with an unmanned aerial vehicle to ensure separation from other aircraft and obstacles.
2. BVLOS - (Beyond Visual Line of Sight) operations out of sight of an unmanned aerial vehicle operator.
3. INS - Authorization to train drone operators.

UAV used improperly or by unauthorized persons may become a hazard sources of potential danger. Along with the popularity of UAV, the number of undesirable events involving them, and events that may cause starts is increasing [4-5]. There are cases in which outsiders are injured (e.g. in Seattle in 2015 - two people were injured, including one severely during a UAV impact [2]).

The number of UAV related events in Poland in 2015 was 19. It should be remembered that these are only those cases that were reported for a business response. Undesirable events in which losses are final are not reported.

To identified were Sources hazards, the possibilities of the Bow-Tie method were used. The method consists of 8 components, which are shown in Table 2. For the purposes of this study, only the right side of the diagram was used (Fig. 4).

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DESINATION</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Area of analysis" /></td>
<td>Area of analysis</td>
<td>Indication of areas of analysis: name of the area, its control (control measures), the scale to which it relates and the context</td>
</tr>
<tr>
<td><img src="image" alt="Top event" /></td>
<td>Top event</td>
<td>Identification of the initiating event, i.e. the state of the analysis area that can cause a loss.</td>
</tr>
<tr>
<td><img src="image" alt="Threat" /></td>
<td>Hazard sources</td>
<td>Identification of sources hazard, which activation may cause Top Event.</td>
</tr>
<tr>
<td><img src="image" alt="Consequence" /></td>
<td>Consequence</td>
<td>Wording of undesirable events giving rise to losses.</td>
</tr>
<tr>
<td><img src="image" alt="Risk reduction measures for hazard sources" /></td>
<td>Risk reduction measures for hazard sources</td>
<td>Identifying risk reduction measures to reduce the likelihood of a Top Event.</td>
</tr>
<tr>
<td><img src="image" alt="Risk reduction measures for consequence" /></td>
<td>Risk reduction measures for consequence</td>
<td>Identify devices and actions taken to reduce the effects that undesirable events can cause.</td>
</tr>
<tr>
<td><img src="image" alt="Escalation factor" /></td>
<td>Escalation factor</td>
<td>Wskazanie okoliczności zmniejszających skuteczności środków redukcji ryzyka (mechanizmu osłabiania bariery).</td>
</tr>
<tr>
<td><img src="image" alt="Escalation factor control" /></td>
<td>Escalation factor control</td>
<td>Definition of control measures that suppress conditions that limit the effectiveness of primary / essential barriers.</td>
</tr>
</tbody>
</table>

A detailed description of the method and the possibilities of using it can be found, among others, in [6].

Bow-Tie method application:
1. Step one identification (indication) of the analysis area.
   Area - Performing UAV flights in the city of Poznań
2. Step two will indicate the loss of control in the analysis area.
   Top Event - Loss of control over UAV
3. Step tree hazard sources identification (hazard sources: Fig. 4 and Table 3).
4. Step four identifying risk reduction measures to reduce the likelihood of a Top Event (risk reduction measures: Table 3).

Fig.4 Identification of hazard sources

<table>
<thead>
<tr>
<th>Hazard sources</th>
<th>Risk reduction measures</th>
<th>Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not checking UAV technical condition before flight</td>
<td>Mandatory technical inspections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regulations and procedures</td>
<td></td>
</tr>
<tr>
<td>Bird clusters in the area of flights</td>
<td>Checking the area before flight</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Falconer employment</td>
<td></td>
</tr>
<tr>
<td>No operator license</td>
<td>Inspections</td>
<td></td>
</tr>
<tr>
<td>No permission to fly</td>
<td>Fine penalties</td>
<td></td>
</tr>
<tr>
<td>Flights in built-up areas</td>
<td>Mandatory permits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The need to have permissions</td>
<td></td>
</tr>
<tr>
<td>Bystanders in areas</td>
<td>Information about flights</td>
<td></td>
</tr>
<tr>
<td>UAV weight over 25 kilogram</td>
<td>Additional rights</td>
<td></td>
</tr>
<tr>
<td>Too high flights</td>
<td>Compliance with laws</td>
<td></td>
</tr>
<tr>
<td>Communication break between UAV and operator</td>
<td>Charging UAV before flight</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Checking the technical condition before flight</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The right equipment selection</td>
<td></td>
</tr>
<tr>
<td>Atmospheric conditions</td>
<td>Flight planning according to weather forecasts</td>
<td></td>
</tr>
<tr>
<td>Plantings</td>
<td>Appropriate selection of area for flights</td>
<td></td>
</tr>
<tr>
<td>UAV system failure</td>
<td>UAV equipment with security systems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Service in accordance with the instructions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Properly trained operator</td>
<td></td>
</tr>
<tr>
<td>Human failure</td>
<td>Training</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Procedures</td>
<td></td>
</tr>
<tr>
<td>Other UAV too close</td>
<td>Proper flight preparation</td>
<td></td>
</tr>
</tbody>
</table>

All identified hazard sources available in Table 3. Acting towards the use of minimal risk for the actions taken after finding the search results for the selection of risk measures.
The use of risk reduction measures is one way of dealing with threat risk in the generally accepted risk management method. The purpose of risk reduction measures is to reduce the likelihood of an undesirable event. Risk reduction measures can include procedures, devices, machines but also human behavior. For 14 identified threats, risk reduction measures were selected (Table 3). The effectiveness of their action was assessed using colors, as is the case with the Bow-Tie method. The performance measures are: yellow - unknown, orange - poor, green - good, dark green - very good.

Fig. 5 shows an example of path.

Fig. 5 The examples risk reduction measures for hazard source with degrees of effectiveness

Scientists estimate that about 64% of UAV-related events are their technical mechanisms [9]. Nevertheless, there is no shortage of unwanted events using UAV by losing the operator's function with equipment or hitting the drone in the building.

Identifying data sources and selecting them to apply risk measures can improve safety when traveling in urban areas.

3. Conclusions

The agglomeration of the city of Poznań is located in a large, densely populated area over which there is intensive air traffic, both civil and military. In addition, the number of UAV flights is constantly growing up. The provisions of the law in force in Poland allow you to fly in virtually any place in the airspace, if you get permission fly from the managers of individual zones.

The growing number of missions carried out by unmanned aircraft used in many areas of human activity forces operators of these vessels to perform a detailed analysis of the hazard sources and then to assess the risk. The growing popularity and availability of UAVs mean that they are the cause of a large number of undesirable events. Undesirable events are caused by improper equipment selection, lack of operator experience but also flight environment. Identifying the hazard sources allows taking action to reduce the likelihood of an event. Appropriate selection of risk reduction measures allows us to carry out air operations with the lowest possible risk of threats. The article uses the possibilities of the Bow-Tie method. 14 sources of threats for UAV flights performed in urban areas were identified. Risk reduction measures and their effectiveness assessed.

References

10. Website: https://www.google.com/maps/d/viewer?mid=1cOwyyB0F5ZW0n2jbv0pX59fO1xM&hl=en_US&ll=52.57643687045852%2C18.601954852349984&z=5 [online cit.: 2020-06-10].
The Impact of the Telematics Systems Using in the Road Freight Transport Business

J. Kubáňová¹, I. Kubasáková², K. Špruncová³

¹University of Zilina, Univerzitna 8215/1, 01026 Zilina, Slovak Republic, E-mail: jaroslava.kubanova@fpedas.uniza.sk
²University of Zilina, Univerzitna 8215/1, 01026 Zilina, Slovak Republic, E-mail: iveta.kubasakova@fpedas.uniza.sk
³University of Zilina, Univerzitna 8215/1, 01026 Zilina, Slovak Republic, E-mail: spruncova@stud.uniza.sk

Abstract

The development of the company is also connected with the development of transport in all its branches. Especially in road transport, the number of means of transport on the roads as well as new drivers are increasing every year, which is associated with many negative phenomena associated with the creation and functioning of the transport system. These are, in particular, the growing number of road accidents, threats to human health and life, and traffic congestion, collapses and other negative effects. Transport telematics creates basic conditions for quality communication and information society, while in terms of transport and its processes they open up new possibilities for achieving sustainable mobility in connection with the sustainable development of society. The basic functions of telematics systems also include fleet management in a transport company. The article focuses on the possibilities of using the vehicle's telematics system for a transport company.

KEY WORDS: telematics system, safety, carrier, route planning

1. Introduction

The 21st century offers us the opportunity to use a variety of telecommunications and information technologies that make work easier for people. In a transport company, it is very important to transmit information at a distance and that this information is usefully processed. For this purpose, transport companies have the opportunity to use telematics equipment, which is dedicated to this paper. When we use telematics together with the route planner, our work can efficiency increases [8]. Telematics simplifies the work of the transport company, especially with its optimal use it can save costs within the company, most often it is about savings related to fuel consumption.

The use of telematics leads to increased driver safety, fewer accidents, a significant reduction in fuel consumption and thus a reduction in CO₂ emissions. This emerges from the global LeasePlan Mobility Monitor survey conducted by the independent agency TNS among 3,377 drivers in 20 countries around the world [14].

Exactly 35% of drivers said they would change their behaviour if a telematics device were installed in the car.

Telematics enables almost real-time data collection. The data is collected directly in the vehicle and is used, for example, to monitor the number of business and private kilometres, fuel consumption, but also the behaviour of drivers, it allows analysis of accidents or the location of vehicles, even after their theft. Telematics works in the vehicle through a device that is easy to install. The data is temporarily stored in a telematics device that is installed in each vehicle, and is then transmitted at regular intervals via GPRS, GSM and to secure servers. It is this central data hub that enables fleet management software to provide easy-to-understand visualizations that help fleet managers optimize their operation. More and more companies use telematics to improve employee safety, increase environmental friendliness, productivity, but also the profitability of their fleets [5, 12, 14].

![Fig. 1 Fleet Management System](image)

The portal can increase the quality of the services offered by allowing customers to provide the location of the
vehicle for inspection. Fleet management connects the truck driver with the dispatcher in the office (Fig. 1).

2. Information from the Telematics System of the Vehicle

More and more transport companies are using telematics to improve employee safety and environmental friendliness, productivity and fleet profitability [1, 12].

Telematics equipment in the vehicle monitors data such as:
- distance (total distance in km for vehicle during the period);
- odometer (vehicle’s mileage at the end of the period);
- fuel consumption (the calculates fuel consumption of the vehicle while driving and idling);
- engine braking (distance travelled during the period when fuel was injected into the vehicle’s engine);
- harsh breaking (the average number is recorded, which shows how many hard breaks);
- idling (engine running time when the engine was idling, this is calculated when the vehicle speed is less than 4 km / h and all power take-offs are disconnected);
- speeding (engine running time when the engine speed has exceeded the upper limit and fuel has been injected, only cases where the speeding lasted longer than 10 seconds are counted);
- carbon dioxide (calculated carbon dioxide emissions per vehicle during the period, includes carbon dioxide emissions generated when the vehicle was running, when the engine was idling and when power take-offs are used) [2, 15].

All the above information is processed in the table for each monitored period. In the following Table 1 you can see a monthly overview of monitored data.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Odometer (km)</th>
<th>Distance (km)</th>
<th>Engine breaking (%)</th>
<th>Idling (%)</th>
<th>Speeding (%)</th>
<th>Harsh braking (#/100 km)</th>
<th>Fuel consumption (l/100km)</th>
<th>CO₂ (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>34166</td>
<td>12862</td>
<td>24.2</td>
<td>11.8</td>
<td>1.4</td>
<td>2.5</td>
<td>27.4</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>24796</td>
<td>7546</td>
<td>13.8</td>
<td>15.0</td>
<td>0.1</td>
<td>8.8</td>
<td>54.2</td>
<td>12.5</td>
</tr>
<tr>
<td>C</td>
<td>63406</td>
<td>13916</td>
<td>23.8</td>
<td>6.6</td>
<td>0.4</td>
<td>1.5</td>
<td>24.3</td>
<td>8.9</td>
</tr>
<tr>
<td>F</td>
<td>38884</td>
<td>6067</td>
<td>12.0</td>
<td>15.7</td>
<td>0.0</td>
<td>8.0</td>
<td>45.4</td>
<td>11.3</td>
</tr>
<tr>
<td>G</td>
<td>52870</td>
<td>5539</td>
<td>17.9</td>
<td>15.1</td>
<td>0.0</td>
<td>7.7</td>
<td>45.4</td>
<td>9.2</td>
</tr>
<tr>
<td>H</td>
<td>115504</td>
<td>11188</td>
<td>27.7</td>
<td>10.5</td>
<td>0.6</td>
<td>0.5</td>
<td>26.7</td>
<td>7.9</td>
</tr>
<tr>
<td>I</td>
<td>190739</td>
<td>15124</td>
<td>21.8</td>
<td>6.2</td>
<td>1.3</td>
<td>0.5</td>
<td>25.9</td>
<td>10.3</td>
</tr>
<tr>
<td>J</td>
<td>314946</td>
<td>13100</td>
<td>23.0</td>
<td>9.9</td>
<td>0.6</td>
<td>0.1</td>
<td>25.6</td>
<td>8.8</td>
</tr>
<tr>
<td>K</td>
<td>3562</td>
<td>2563</td>
<td>9.7</td>
<td>16.4</td>
<td>0.0</td>
<td>0.0</td>
<td>46.5</td>
<td>-</td>
</tr>
<tr>
<td>L</td>
<td>202218</td>
<td>8577</td>
<td>16.4</td>
<td>18.4</td>
<td>0.3</td>
<td>2.5</td>
<td>33.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Average</td>
<td>104109</td>
<td>9648</td>
<td>19.0</td>
<td>13.0</td>
<td>3.0</td>
<td>35.4</td>
<td>9.6</td>
<td></td>
</tr>
</tbody>
</table>

This data is sent by the unit from the vehicle to the central of the company, which manages and manufactures the telematics. Thanks to this, not only the carrier has control over the result, but also this company, which, based on all the results, can advise the carrier on how the ride could be even better [3, 9].

The fleet management web portal offers data such as:
- **Ability to monitor the current position of the fleet** - the position is updated every 10 minutes (in 10 minutes of inactivity, the telematics will send feedback on the position). Figure 2 shows a map with the location of the vehicle fleet, where after clicking on the vehicle icon on the map, we can see the detail of the vehicle. In the detail of the vehicle data such as vehicle position, current vehicle speed, total distance travelled and displayed fuel level together with AdBlue.
- **Ability to see on the map in the system all restrictions on the road**, traffic signs (restrictions with regard to load, maximum permitted width and height) and also the location of service centres for vehicles.
- **Ability to see the driver’s current work mode** such as driving, taking a break, or other work. The modes can be seen in Figure 3.
- **Geographic zone setting** (this setting has many advantages, e.g. the system can notify suppliers that the vehicle is approaching, so you can avoid the number of phone calls before loading or unloading, this setting can also limit the driver from parking at the house or prevent the entry of the vehicle into the emission zone).
- **Notification of faults and defects on vehicles** (Figure 4).
- **Ability of service planning** (planning is flexible; it depends on the number of kilometres travelled. Once a month, the system evaluates the engine load and load in tonne-kilometres, the output can be seen on the telematics portal). E.g. the next service is planned for the vehicle in figure 5 on October 27, 2020 [3, 6, 14, 15].
3. Data on a Specific Route Obtained from the Vehicle’s Telematics System

As a practical example, we will present a specific transport route from the Czech Republic to Germany (Fig. 6.), with several unloadings, specifically in:

- Bad Soden Salmünster;
- Langenselbott;
- Fulda;
- Schlitz and
- Großenlüder.

As these are regular customers, unloading contains packaging material that travels back to the Czech Republic, i.e. the vehicles do not make empty journeys.
The following data was obtained from the telematics device on this route:

- total distance: 1869.7 km;
- average fuel consumption: 26.5 l/100 km;
- total engine running time: 25 hours 41 minute;
- engine idling time: 50.5 minute;
- distance travelled on cruise control: 1540 km;
- CO₂ value: 1385.67 kg;
- actually map position of the vehicle;
- driver’s driving style analysis and comparison, etc.

4. Data on a Specific Route Obtained from the Map and Guide Program

Route planning is the task of the dispatch department of the transport company. The dispatcher is responsible for a correctly and safely planned route, including the possibility of taking safety breaks and rest in secure parking areas. We wrote about the possibility of using secured parking areas in my past papers.

The Map and Guide program is used by transport companies mainly for route planning and optimization. When the dispatcher planes routes, Map and Guide calculates the estimated time of arrival of trucks at the destination. Thanks to an approximate estimate of the vehicle's arrival at the destination, it is possible to adjust the loading or unloading time. The program also offers flexible route optimization that is suitable for road freight transport. If the route contains unwanted ferry sections, low-emission zones or narrow roads, they can be excluded in the settings.

This program is adapted primarily for the planning of truck routes, i.e. the calculation of the journey time takes into account the restrictions on speeds but also on traffic signs that apply to this category of vehicles. Map and Guide allows you to calculate the amount of greenhouse gas emissions produced and the energy consumption of vehicles before the vehicle leaves. The transport company can thus optimize its route in terms of emissions. Map and Guide calculates emissions based on the vehicle used, its weight and the increase in altitude on the planned route [5, 9, 10].

Furthermore, this program allows the calculation of the cost of tolls in road transport. Toll charges are collected from toll suppliers and then automatically integrated into the Map and Guide toll cost calculator, so there is no need to perform these calculations manually. The program determines the exact calculation of the toll based on which vehicle is chosen for a given transport route [4, 13].

With the help of the Map and Guide route planner, it is possible to evaluate the gross minimum wage and the wage costs of truck drivers. Thanks to route planning software, drivers' wages are calculated automatically and compared with the minimum wage regulations of individual countries. This will ensure that the transport company complies with national legal requirements. Surcharges are only added to the actual working hours in the defined countries [7, 13].

The route planner can also collect and update information on truck waiting times at border crossings and then display it on a map.

For a possible comparison of the obtained data with telematics, a specific route is chosen identical.

The circles shown on the map, which are marked in green, represent current information on the waiting times of vehicles for crossing at border crossings. The circles marked in black mean that there is no current waiting time data and the orange circle represents a waiting time of more than 10 minutes.

The following data was obtained from Map and Guide program on this route (Fig. 7):

- total distance: 1818.24 km;
- total fuel consumption 510.70 l;
• average fuel consumption: 28,09 l/100 km;
• CO₂ value: 1347,53 kg, NOx value: 567,55 g, N₂O value: 90,96 g, CH₄ value 1,12 g;
• tolls: 285,35 EUR.

 Fees for the using of the compared systems are:
• Map and Guide: 588 € per year / 1 user;
• Telematics system (Fleet management): it depends on the manufacturer, but prices range from € 250 - € 750 per year / 1 user.

![Fig. 6 The planned route using map and Guide program [13]](image)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Fleet management</th>
<th>Map and Guide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total distance</td>
<td>1869,7 km</td>
<td>1818,24 km</td>
</tr>
<tr>
<td>Average fuel consumption</td>
<td>26,5 l / 100 km</td>
<td>28,09 l / 100 km</td>
</tr>
<tr>
<td>Total engine running time</td>
<td>25 h 41 min</td>
<td>-</td>
</tr>
<tr>
<td>Engine idling time</td>
<td>50,5 min</td>
<td>-</td>
</tr>
<tr>
<td>Distance travelled on cruise control</td>
<td>1540 km</td>
<td>-</td>
</tr>
<tr>
<td>Tolls</td>
<td>-</td>
<td>285,35 €</td>
</tr>
<tr>
<td>CO₂ value</td>
<td>1385,67 kg</td>
<td>1347,53 kg</td>
</tr>
<tr>
<td>NOx value</td>
<td>-</td>
<td>567,55 g</td>
</tr>
<tr>
<td>N₂O value</td>
<td>-</td>
<td>90,96 g</td>
</tr>
<tr>
<td>CH₄ value</td>
<td>-</td>
<td>1,12 g</td>
</tr>
</tbody>
</table>

5. Conclusion

Telematics has found its place in the transport sector. The carrier is looking for ways to improve the services offered to customers while saving costs. And it is telematics that helps him in this, he can monitor fuel consumption, reduce the impact on the environment and save costs for the transport company. Setting the right and efficient ride leads to safer driving and better vehicle efficiency. Another advantage that telematics devices bring is the constant online monitoring of the vehicle and the transported consignment. There is certainly an option for improvement in the future, such as reducing the cost of the most cost-effective telematics or improving telematics so that the technology provides the consumer with the most valuable information. It is also presumably that we will see that telematics puts more emphasis on usability, making it more accessible to the current consumer. The benefits of using telematics are clear and help shape the future of the freight and logistics industry [8]. We may see the use of telematics has become more standardized, but we are sure to see the technology become more finely tuned to maximize the potential advantages.

For the optimal use of telematics equipment and planners, we would suggest that if a company enters the market in order to operate a business in road freight transport and begins, for example with only one vehicle, so in this case, the company will suffice for its activities using route planners such as Map and Guide. The company could then gather all
the necessary information not only from the route planner, but also from the vehicle's tachograph.

Acknowledgements

This paper was developed under the support of project: MSVVS SR - VEGA No. 1/0245/20 Poliak, M.: Identification of the impact of a change in transport related legislation on the competitiveness of carriers and carriage safety

References

11. https://www.google.sk/maps
15. Internal data of the transport company
Application of Infeasible Region Parameters for Prevention Collisions by Ships

O. Burmaka 1, O. Volkov 2, T. Omelchenko 3, I. Petrichenko 4

1 National University «Odessa Maritime Academy», Didrikhson 8, 65029, Odessa, Ukraine, E-mail: burmaka2007@gmail.com
2 National University «Odessa Maritime Academy», Didrikhson 8, 65029, Odessa, Ukraine, E-mail: volkov55@bigmir.net
3 National University «Odessa Maritime Academy», Didrikhson 8, 65029, Odessa, Ukraine, E-mail: marineofficer.ua@gmail.com
4 National University «Odessa Maritime Academy», Didrikhson 8, 65029, Odessa, Ukraine, E-mail: ievpetrichenko@gmail.com

Abstract

Methods of formation of infeasible region parameters designated for assessment of close quarters situation existence upon the condition of local independent control of ship’s passing process have been considered. The possibility of application of computer technologies for graphic representation of infeasible region parameters in close quarters situation with one or two targets has been shown. An example of a ship’s passing manoeuvre parameters calculation has been presented using a computer program.

KEY WORDS: the safety of navigation, ship’s passing process, local independent steering, infeasible region parameters

1. Introduction

High risk of collision of ships that are approaching each other is mainly stipulated by the imperfect procedure of determining of close quarters situation and the absence of a simple and operational method of making decisions on safe manoeuvre selection which depends on the extent of the risk of collision. As the avoidance manoeuvre by altering course is preferable if there is sufficient sea room, it is necessary to form a selection method of ship’s evasive manoeuvre for safe passing.

The autonomous system of evading collisions «CA» (Collision avoidance) and its theoretical background has been considered in paper [1]. Taking into account the factors affecting the process of evading collisions, the requirements for autonomous navigation have been considered. The paper indicates that studies on automatization of ship’s steering may be represented in classic or computer approach. In the theoretical direction the paper doesn’t contain recommendations on practical navigation. In papers [2-4] it has been stated that the task of selection of proper avoidance manoeuvre is very complex as the process of ship’s steering is multivariate with nonlinear and unsteady characteristics wherein the task is game-like.

Implementation of a particular type of interaction between ships in case of situational disturbance of various types has been considered in paper [5], and paper [6] is focused on the formation of flexible strategies of passing which depend upon the value of situational disturbance. A contingent passing strategy in close quarters situation has been suggested in paper [7].

Paper [8] is focused on the study of optimal selection of binary coordination system structure of interaction of a pair of ships in close quarters situation in course of passing. Papers that are subjected to analysis make a significant contribution to the theory focused on the decision making process in collision prevention although they do not contain recommendations on the prompt selection of avoidance manoeuvres.

Recently the studies on the provision of safe passing of ships by means of external steering methods with application of infeasible regions of courses or speeds have appeared [9]. The suggested approach for collisions prevention by ships is considered to be reasonable under local independent control of the ship’s passing process with the application of infeasible region parameters of ship’s movement which can be implemented via computer as an operational procedure on ship’s passing manoeuvre. The present article is focused on this issue.

The objective of the present article is the consideration of procedure of ship’s close quarters’ situation assessment, with purpose or in the case of need, selection of avoidance manoeuvre by alteration of course by means of infeasible region parameters of ship’s movement.

2. Presentation

When a ship is approaching a target with CPA (Closest Point of Approach) \( \text{min} \, D \) which is smaller than the maximum permitted distance \( d_j \), approaching is dangerous. The value of CPA \( \text{min} \, D \) depends on bearing on a target \( \alpha \) and distance \( D \) between ship and target as well as on the ship’s movement parameters (course \( K_i \), speed \( V_i \)) and target
(course $K_2$, speed $V_2$) [5]. At given values $\alpha$, $D$, $K_2$ and $V_2$ the multitude of combinations of ship’s movement parameters exists. $K_1$ and $V_1$, wherein there is inequality $\min D \leq d_d$. If combinations $K_1$ and $V_1$ are considered as coordinates $(K_1, V_1)$ of coordinate plane $K_1 \times V_1$, region $\Omega_d$, for each coordinate $(K_1, V_1)$ which performs inequality $\min D \leq d_d$, is infeasible region parameter of ship’s movement.

It is obvious that, the border of region $\Omega_d$ is combination of coordinates $(K_1, V_1)$, for each of them the equality $\min D = d_d$ is reached. Taking into account that given equality is reached under relative evading of a ship both starboard and port in relation to bearing, there can be two borders which restrict infeasible region parameters of ship’s movement $\Omega_d$. In this case if coordinate $(K_{ii}, V_{ii})$ belongs to region $\Omega_d$, approaching of the ship with a target is dangerous, as $\min D < d_d$. Otherwise, in case of approaching with target the risk of collision does not occur. In paper [9] analytic expressions for borders of region $\Omega_d$ in case $V_i > V_2$, which represent dependences of ship’s course $K_1$ on her speed $V_1$, wherein equality $\min D = d_d$ is correct, for a ship approaching a target on reciprocal courses:

$$K_{1(i)}^{(i)} = \gamma^{(i)} + \arcsin \left( \frac{V_2 \sin (K_2 - \gamma^{(i)})}{V_1} \right);$$
$$K_{1(i)}^{(2)} = \gamma^{(2)} + \arcsin \left( \frac{V_2 \sin (K_2 - \gamma^{(2)})}{V_1} \right),$$

where in $\gamma^{(i,2)} = \alpha \mu \arcsin \frac{d_d}{d_d}.$

By means of infeasible region parameters of ship movement $\Omega_d$, it is possible to evaluate whether close quarters situation with a target exists. For this purpose it is sufficient to check the relation of coordinate to ship’s movement parameters $(K_1, V_1)$ region $\Omega_d$. If $(K_1, V_1) \in \Omega_d$, approaching is dangerous, otherwise ship and target are approaching safely. In case of close quarters situations with help of region $\Omega_d$ it is possible to select avoidance manoeuvre by altering course of a ship without speed alteration. Coordinate $(K_{1y}, V_1)$ corresponds to such a manoeuvre, and is located on the border of region $\Omega_d$.

A suggested procedure of evaluation of the risk of close quarters situation with a target and selection of avoidance manoeuvre by evading with the help of region $\Omega_d$ in case $V_i > V_2$ has been performed via computer program which in its turn has provided operation and simplicity of performance of a given task. The formation of region $\Omega_d$ has been shown for close quarters situation with parameters: $\alpha = 128^\circ$, $D = 3.5$ miles, $K_1 = 100^\circ$, $V_1 = 22$ knots, $K_2 = 350^\circ$, $V_2 = 17$ knots, $d_d = 1$ mile.

By means of equations (1) borders of infeasible region parameters of a ship have been calculated $\Omega_d$, which are shown in the Fig. 1. Region is given in system of coordinates of ship’s movement parameters. Each coordinate $(K_1, V_1)$ of ship’s movement parameters, which is located between borders of region $\Omega_d$, is characterized by closest point of approach $\min D$ which is smaller than maximum permitted distance $d_d$, which shows close quarters situation. As for the given example coordinate with initial parameters of ship’s movement $(K_1 = 100^\circ, V_1 = 22$ knots), which is located in the intersection of corresponding horizontal and vertical lines belongs to region $\Omega_d$, thus approaching of ship with target is dangerous.

In this connection it is necessary to determine evasive course $K_{1y}$, on which CPA $\min D$ reaches the value, which equals $d_d$. For this purpose the program precedes interactive input of ship’s evasive course $K_{1y}$, and besides indication of input value $K_{1y}$, the change of horizontal line’s position occurs depending upon value $K_{1y}$. Alteration of evasive course $K_{1y}$ is performed until horizontal line reaches the border of region $\Omega_d$, as it is shown in the Fig. 1. In the example considered above the border of region $\Omega_d$ is reached with $K_{1y} = 126^\circ$, wherein $\min D = 1$ mile. Thus, by entering initial parameters of close quarters situation into computer program mentioned above we will obtain graphical image of region $\Omega_d$ and position of coordinate $(K_1, V_1)$ of initial parameters of ship movement. Now we can evaluate visually a relation of coordinate to region $\Omega_d$ and make a conclusion on existence of close quarters situation and necessity of selection of evasive course. In case of necessity by moving scroll box we can combine horizontal line with selected border of region $\Omega_d$, obtaining evasive course of a ship.
In case of close quarters situation with two targets it is reasonable to apply a combined avoidance manoeuvre with subsequent alteration of course to evade the first target and by braking to let the second target pass clear wherein braking commences at the time of reaching the closest point of approach with the first target.

In paper [10] a method of forming region \( V_{K1,V2} \) of permitted combined manoeuvres for passing with two targets by alteration of course and her passive braking has been suggested for a given situation. Three parameters of passing manoeuvre correspond to each coordinate of region \( V_{K1,V2} \): time \( t_y \) and evasive course \( K_1 \) to pass the first target, and also speed \( V_o \), to which initial speed by means of braking is reduced and wherein braking commences at the moment of time \( t_y \).

In this example the given method of calculation of region borders \( V_{K1,V2} \) has been considered with the application of combined avoidance manoeuvre with alteration of her course and subsequent reducing of speed by means of active braking which has been implemented via developed computer simulation program. As an example the close quarters’ situation with the following parameters has been considered: ship’s movement parameters \( K_s = 75^\circ \), \( V_s = 23 \) knots, target movement parameters \( K_1 = 199^\circ \), \( V_1 = 20 \) knots, \( K_2 = 16^\circ \), \( V_2 = 21 \) knots, relative positions of targets \( \alpha_1 = 36^\circ \), \( D_1 = 3 \) miles, \( \alpha_2 = 135^\circ \), \( D_2 = 5 \) miles.

For the given close quarters’ situation region of permitted manoeuvres has been formed \( V_{K1,V2} \), which is shown in Fig. 2. Initial coordinate (Fig. 2) \( (K^{(r,p)}, V_o) \), has been selected and belongs to its border, for which parameters of avoidance manoeuvre have been determined \( K_y = 86^\circ \), \( V_o = 15 \) knots, \( t_y = 284 \) sec, and Fig. 3 shows relatively safe tracks for passing, which are osculatory for safe domains of targets.
3. Conclusions

1) Analytical expressions of formalization of infeasible region parameters of ship movement have been obtained by means of which it is possible to evaluate the danger of approaching with a ship and target and selection of avoidance manoeuvre by alteration of course in conditions when the ship’s speed is greater than the speed of a target.

2) Implementation of the suggested procedure with the help of a computer program has been suggested and an example of determining of evasive course of the ship approaching a target has been suggested. Operation and simplicity of close quarters situation evaluation and selection of avoidance manoeuvre have been justified.

3) Combined manoeuvre for the passing of ship with two targets by means of course alteration and her subsequent active braking has been considered.

References

Research of LPG use in Diesel Engines

I. Akūnis¹, D. Juodvalkis²,³

¹Kaunas University of Technology, Studentu 56, 51424, Kaunas, Lithuania, E-mail: ignas.akunis@ktu.lt
²Kaunas University of Technology, Studentu 56, 51424, Kaunas, Lithuania, E-mail: darius.juodvalkis@ktu.lt
³Kaunas University of Applied Engineering Sciences, Tvirtovės av. 35, 50155, Kaunas, Lithuania, E-mail: darius.juodvalkis@edu.ktk.lt

Abstract

Diesel-powered cars, especially commercial ones, are still the most popular. One way to improve the dynamic performance and lower pollution of diesel engines is to adapt them to dual fuel (diesel + LPG). In the article the possibilities of adapting the diesel car BMW 320d E46 to dual fuel are reviewed and field experiments to determine the dynamic characteristics of this car's engine using dual fuel are performed.

KEY WORDS: diesel engine, LPG, dual fuel

1. Introduction

Road transport is one of the biggest sources of pollution on our planet. Recently, road transport has undergone changes, trying to move away from diesel-powered cars to more environmentally friendly vehicles that run on alternative fuels or electricity. Diesel cars are still the most popular all over the world, especially in Europe. Unlike petrol-powered engines, which can only run on gaseous fuels, diesel engines may use two kinds of fuel if adapted to gaseous fuels: diesel fuel and a mixture of gaseous fuels. Diesel engines can be adapted to LPG-diesel fuel without major modifications. When adapting a diesel internal combustion engine to dual fuel, first the unit must be minimally modified. The main changes are made in the engine components by installing additional connections in the fuel supply, electrical installation, exhaust systems.

Depending on the operating mode of the engine, gaseous fuels can replace up to 40% of diesel fuel. The use of dual fuels (diesel + LPG) in diesel engines makes it possible to achieve better engine dynamic performance, reduce emissions and achieve a positive economic effect.

The possibilities of using dual fuel in a diesel engine and their positive impact on engine emissions have been analysed by Indian scientists [1]. The use of gaseous fuels in the diesel-powered Toyota Hilux engine has been analysed by Polish scientists, who have found that the engine torque increases by about 20%, the resulting fuel efficiency is about 30% and no negative impact on engine lifespan was observed [2].

In the article the dynamic performance of a dual-fuel engine in the BMW-320d E46, which is equipped with the TE-GD4 liquefied petroleum gas system, is reviewed.

2. Research Methodology and Equipment

The BMW-320d E46 was used for the research. The technical performance of the car engine is presented in Table 1.

<table>
<thead>
<tr>
<th>Engine performance [3]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine type</strong></td>
</tr>
<tr>
<td><strong>Fuel system</strong></td>
</tr>
<tr>
<td><strong>Compression ratio</strong></td>
</tr>
<tr>
<td><strong>Maximum power</strong></td>
</tr>
<tr>
<td><strong>Maximum torque</strong></td>
</tr>
<tr>
<td><strong>Engine code</strong></td>
</tr>
</tbody>
</table>

There are currently a number of diesel / gas kits from major alternative fuel manufacturers on the market, made by different manufacturers of gas equipment and components: Elpigaz DEGAmix, Car-Gaz Solaris Diesel, Europegas OscarN Diesel, Femitex MA-X8, Autogas Dual System Fly Diesel Plus, STAG DIESEL, Tegas TE-GD4. All of these systems can be used in both passenger cars and commercial vehicles. The Tegas TE-GD4 alternative fuel system was selected for the research car (Fig. 1). This system was chosen because it is manufactured in Lithuania and the manufacturer guarantees high-quality and full technical support in terms of system installation, adjustment and operation. The main advantages of this equipment: lambda sensor maintenance, it can be used for diesel vehicles with up to 16 cylinders, automatic adjustment system, automatic calibration, compatible with all diesel fuel systems, suitable
for LPG and CNG, integrated engine overheating protection, compatible with detonation sensor, gas injection can be performed with 1-4 injectors, TPS emulation.

The principle of operation of this system is based on the fact that the system reads the readings of the car’s TPS sensor and sends a TPS signal to the car’s engine control unit by reducing it. Depending on how much the TPS sensor signal is reduced, the system supplies additional gaseous fuel through the injectors. The injectors may be installed separately for each cylinder in the intake manifold, or one or more injectors at the beginning of the intake manifold, regardless of the number of cylinders in the engine. The schematic diagram of the Tegas TE-GD4 system in the car is presented in Fig. 2 [4].

LPG after evaporation in the reducer is mixed with the intake air in the intake manifold, and the diesel fuel injection system still supplies a certain amount of diesel fuel, but in dual fuel mode, the amount of diesel injected is reduced in proportion to the petroleum gas introduced / injected into the intake manifold.

Depending on the engine operating mode, up to 40% of diesel fuel can be replaced by gas fuel. Exhaust temperature and detonation sensors are integrated in the Tegas TE-GD4 system. Based on the readings of these sensors, the system automatically adjusts the composition of the combustible mixture by changing the ratio of diesel to gaseous fuel. The mass fraction $Z$ of LPG fuel used in dual fuel mode is calculated by the expression:

$$ Z = \frac{m_{LPG}}{m_{diesel} + m_{LPG}} \cdot 100\% \quad (1) $$

Negative phenomena such as detonation and intermittent ignition can occur during the combustion process [5].
They are caused by excessive concentration of gaseous fuels. The portions of gaseous fuels entering the combustion chambers must be optimal to avoid phenomena which adversely affect the combustion process. Increasing the initial amount of diesel fuel injection can reduce engine detonation during engine loading. In LPG dual-fuel engines, the maximum pressure is always higher than in diesel-only engines. This is due to the higher combustion temperature for gaseous and diesel fuels. Increasing the LPG ratio in dual fuel mode causes two phenomena. First, the combustion and propagation rates of the blended mixture increase, but at the same time the combustion stability decreases, which can be increased by the more abundant amount of diesel injected. Second, the reduced amount of injectable fuel injects reduces the number of ignition sources, thus increasing the path that the flame has to spread in order to burn the entire mixture in the combustion chamber.

During the research, DL1 Data Logger measuring instruments were used to determine the acceleration speed and time of the BMW 320d E46. The data recorded by DL1 Data Logger was used in calculations and analysis of results. During the tests, the position of the measuring equipment was such that the axes x, y, z of the coordinate system coincided with the coordinate system of the vehicle. The position of the equipment in the car and the preparation for the measurements are shown in Fig. 3.

![Fig. 3 Measuring equipment DL1 Data Logger: a – inside car; b – outside car](image)

The experimental measurements were performed in a place with a smooth and clean asphalt road surface. The temperature during the research was +7 - +10°C. During the tests, the acceleration time and speed of the vehicle were recorded. During the tests, the throttle must be fully opened in petrol internal combustion engines and the fuel in the combustion chamber must be fully supplied in diesel engines in order to obtain accurate engine dynamic characteristics.

During the experiments, the acceleration of the BMW 320d E46 in third gear was measured. The experiments were performed in the following order:
1. Acceleration to a speed of 28 km/h;
2. Gear 3 is engaged;
3. The accelerator pedal is fully depressed;
4. The accelerator pedal is released when the speed reaches 100 km/h.

The time dependences on speed and acceleration of the car movement are obtained during the experiment. These dependencies obtained with the DL1 Data Logger are shown in Fig. 4.

![Fig. 4 Results obtained with DL1 Data Logger: a - speed; b – acceleration](image)

For more accurate results, the experimental tests were performed four times and the results of the mathematical average were used to calculate the dynamic properties of the car engine.

3. Research Results

After performing experimental ride, during which the dynamic properties of the car (speed and acceleration) were measured during acceleration, when the car's engine was running in different modes (diesel and dual fuel mode only) and knowing the car's performance, the engine torque was calculated (2):
\[ M_e = \frac{r_s}{u_{g3} \cdot u_{gm} \cdot \mu_t} \left( C_d \cdot A \cdot \rho \cdot v^2 - f_0 \left( 1 + \frac{v^2}{1800} \right) - m \cdot a \right), \]

here \( r_s \) – static radius of the wheel; \( u_{g3} \) – gear ratio of third gear; \( u_{gm} \) – gear ratio of main gear; \( \mu_t \) – transmission efficiency; \( C_d \) – value of aerodynamic drag; \( A \) – car frontal area; \( \rho \) – air density; \( v \) – car speed; \( f_0 \) – value of tire resistance to rolling; \( m \) – car weight; \( a \) – car acceleration.

In Fig. 5 the obtained dynamic characteristics of the engine are presented when the engine is running in different modes - only for diesel fuel and dual fuel (diesel + LPG).

Analysing the dynamic performance of the engine presented in Fig. 5, it can be observed that the engine develops a higher torque when the engine is running in dual fuel (diesel + LPG) mode. A significant difference is observed when the engine speed is about 2000 RPM, then the maximum engine torque is obtained when the dual fuel (diesel + LPG) supplied to the engine is about 400 Nm. With the engine running on a standard diesel mixture, the maximum torque developed is around 330 Nm and it is reached at 2200 RPM. When the engine speed is higher (3000 - 4000 RPM), there is no significant difference in the dynamic characteristics of the engine operating in different fuel modes - in each case the engine reaches a torque of about 320 Nm. Dual-fuel systems for diesel engines are not yet widely used in automobiles, and their operating modes are still being improved, so it is likely that better programming of the system's operating parameters will result in better engine performance in all operating modes.

4. Conclusions

1. Diesel engines in modern cars can be successfully adapted to use dual fuel (diesel + LPG).
2. The use of LPG fuels in diesel engines improves their dynamic performance and is cost-effective.
3. Using the dual fuel system Tegas TE-GD4 in the BMW 320d E46 diesel engine M47D20TU when the engine speed is 2200 RPM, its maximum torque is increased by about 20% - from 330 Nm to 400 Nm.

References

Security Barriers against Moving Vehicles

P. Maňas¹, J. Štoller², P. Dvořák³

¹University of Defence in Brno, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: pavel.manas@unob.cz
²University of Defence in Brno, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: jiri.stoller@unob.cz
³University of Defence in Brno, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: petr.dvorak@unob.cz

Abstract

The paper deals with the topic of security barriers against moving vehicles that are widely used both in the public and in the private sector. Also in the military, the crucial question of force protection of a military base against vehicle ramming attack is acknowledged. The paper focuses on the current state of standardization documents that covers the area of the security barriers against moving vehicles, also known as vehicle security barriers. It also mentions the role of numerical modelling and simulations as a robust tool to test and verify particular qualities of security barriers in special cases where it is not feasible to conduct real crash tests.

KEY WORDS: security barrier, moving vehicle, vehicle-ramming attack, military base, simulation

1. Introduction

The security barriers against moving vehicles are one of the fundamental parts of the complex physical security systems of countless industrial facilities, buildings of public service, and specifically critical infrastructure objects [1, 2]. Moreover, a huge variety of security barriers is deployed around almost every public space anywhere in the world. Nowadays different sizes and shapes of barriers are very widely used, even to the extent of being virtually unnoticed by the passers-by. Such kind of obstacles can be also found around military bases and compounds in foreign missions that protect both military and civilian personnel against vehicle borne improvised explosive devices.

The design of the physical security system is always based on the optimum balance between the requirements for a secure building and the different types of external threats to the facility. Any comprehensive physical security system must also contain several other elements that enhance the considerable potential of security barriers. Usually, the security system is completed with strong lighting, high-resolution cameras, active and passive sensors or special x-ray imagery devices. In addition, the explicit standoff distance between a building and a fence is required to guarantee the whole system is fully operable, see Fig. 1.

Fig. 1 Example of a physical security system of a critical facility, according to [3]
2. Security Barriers in the Military Environment

Based on valuable experience from recent and ongoing engagements, it can be assumed that in the near future, the Armed Forces of the Czech Republic will be involved in a wide range of NATO operations that could be generally regarded as expeditionary, joint, and multinational. In this sort of operation, the deployed forces are engaged in asymmetric combat activity with an adversary who is using a wide range of weapons from improvised explosive devices to modern anti-tank mortars. One of the distinctive features of these engagements is that the deployed forces must be able to perform several different operations simultaneously, combat, non-combat and humanitarian, and within a restricted geographical area.

This permanent threat against the deployed forces can be defined as omnidirectional and it can occur suddenly without any warning. In such a volatile environment, force protection, as an essential part of the military unit resilience, acquires much greater importance. The security barriers against moving vehicles are an essential part of the force protection of any military base, especially taking a fundamental role as the protection against vehicle borne improvised explosive devices. The security barriers can be found at several points of the perimeter of the military base, see Fig. 2:

- Outside the perimeter of the camp – prefabricated concrete blocks, steel bollards, shaped ditches, soil berms.
- On the perimeter of the camp – prefabricated concrete blocks, steel bollards, beams, gates, tire shredders.
- Inside the perimeter of the camp – prefabricated concrete blocks, steel bollards.

Fig. 2 Example of an entry control point at a military base, according to [4]

3. Security Barrier Testing

The testing, assessment and certification of the security barriers against moving vehicles are dealt with in detail in several national and international technical standards, both civilian and military:

- PAS 68:2013 Impact Test Specifications for Vehicle Security Barrier Systems [5] – the document details a vehicle security barrier classification system and describes two test methods of determining the performance classification of barriers systems, the vehicle impact method and the design method, which includes the use of finite element analysis techniques on condition that they are validated by reliable test data.
- CWA 16221:2010 Vehicle Security Barriers. Performance Requirements, Test Methods and Guidance on Application [7] – the agreement specifies a classification system for the performance of a vehicle security barrier when subjected to a single horizontal impact, but it does not describe the performance of barriers loaded with blast explosion, ballistic impact or manual attack with the aid of tools, and in the annexes, it also provides guidance for the selection, installation and use of the barriers.
- ASTM F2656M-20 Standard Test Method for Crash Testing of Vehicle Security Barriers [8] – the standard describes a test method resulting in a penetration rating for a barrier exposed to a vehicle impact, but only a single specimen test at a specified impact location is required and for that reason specific conditions at a facility are likely to
degrade the barrier’s performance.


Evaluating the results from various experiments described in the above-mentioned documents, an alphanumeric string for the performance of a specific barrier can be determined, see Fig. 3.

![Fig. 3 Example of a label for the performance of a barrier, according to [11]](image)

Within the military environment, the following test procedures examine not only the impact of the vehicle mass on the security barrier, but in the case of a vehicle borne improvised device, also a load of detonation of explosives carried by the vehicle.

- STANAG 2280 Test Procedures and Classification of the Effects of Weapons on Structures [12] – this is a formalized document confirming that the participating parties agree to implement the following publication [13].

- ATP-3.12.1.8 Test Procedures and Classification of the Effects of Weapons on Structures [13] – the publication covers common military projectiles, fragmentation, vehicle and blast weapons, as well as a generalized spectrum of blast threats, which includes the characteristics of the majority of improvised explosive device attacks.

- UFC 4-022-02 Unified Facilities Criteria – Selection and Application of Vehicle Barriers [3] – the document provides a guide to the planning, design, selection, and installation of vehicle barriers used for perimeter protection of guarded facilities.

The common feature in all these documents is a classification of vehicles into several categories from small passenger cars to heavy trucks, moving against the barrier with a certain velocity and impacting it mainly in a perpendicular direction. The main criteria for assessment are a distance, where the car is stopped, and a depth of penetration beyond the barrier, which is critical for military use indicating whether the attack can continue or not.

4. Numerical Modelling and Simulations

The security barrier testing, described in the above-mentioned technical standards, is principally based on field experiments with real vehicles and barriers. Leaving aside the considerable cost of such a type of rigorous testing, there are other obvious disadvantages of this practical approach. Mainly the performance of a certain barrier is usually assessed on a unique set of conditions, which does not guarantee that the barrier will show the same protective level during the repeated tests, and in the possibly a harsh environment at a protected facility. The set of conditions for a car includes its make, type, technical condition, load, weight, velocity, approach angle, and for a barrier, it consists of a type of foundations, soil characteristics, climate and weather or surface friction.

To mitigate the high cost of real tests and to study a wider range of impact scenarios, the numerical modelling and simulations are used during the barrier testing. Due to the enormous number of design parameters, the numerical modelling and simulations need to be repeatedly verified against experimental data, before being able to expand the developed numerical framework to a greater number of impact scenarios and to provide the future users of barriers with detailed and profound insight into the resistance of the barriers [11].

5. Conclusion

One of the most common types of an enemy attack against its own forces in foreign operations is the vehicle
ramming attack against the main entrance of the military base, also called entry control point. This kind of attack is usually associated with the subsequent detonation of a large amount of explosives carried by the vehicle, which is in military terminology called vehicle borne improvised explosive device.

To resist extreme external forces and their particular combination, the ideal security barrier should at least hold the following set of mechanical and physical properties:

- Designed and certified in accordance with the current standardization document.
- Resistant to weather conditions with a sturdy frame and surface finish.
- Easy to store in an ISO container.
- Capable of being moved by air transport.
- Simple to deploy without the necessity of building foundations.
- Movable by the means of transport available to the military units deployed in foreign operations.
- Minimal to none footprint to enable an easy handover of the area to the local landowners.

Acknowledgment

The work presented in this article has been supported by the Ministry of Defence of the Czech Republic through the Department 201 research program “Development of technologies in weapons construction, ammunition, weapons instrumentation, materials science and military infrastructure 2016-2020” at the University of Defence in Brno, Czech Republic.

References

Development of a Digital RIS Index in Ukraine’s Inland Water-Ways in the Process of Implementing the Information Portal of the European Union

A. Raynov¹, M. Kulakov², I. Medvedieva³, J. Oleynik⁴

¹National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: raynovaleksandr@gmail.com
²National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: endeavorlxze1@gmail.com
³National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: medvedieva.onma@gmail.com
⁴National University «Odessa Maritime Academy», Didrihsona 8, 65000, Odessa, Ukraine, E-mail: j0633590714@gmail.com

Abstract

River Information Services (RIS) is based on 4 standards, which includes Inland Electronic Chart Display and Information System (ECDIS), Notices to Skippers (NtS), Vessel Tracking and Tracing (VTT) and Electronic Reporting International (ERI). All these standards are interconnected by a RIS index, with the help of which all objects are digitally encoded displayed on a map, including navigation aids, port facilities, ship passage characteristics, etc. The article discusses some non-trivial examples of RIS indexing in Ukraine’s inland waterways (IWW).

KEY WORDS: RIS index, navigation aids

1. Introduction

The strategy of RIS was accepted in Ukraine and as a result UkrRIS presented information services on the Danube and Dnieper rivers. In the Assistance Program for the project “Transport Development on the Dnieper”, the state of River Information services on the Dnieper should be assessed and proposals for improving and expanding RIS based on the needs and requirements of the Inland Waterway Transport (IWT) on the Dnieper. The prerequisite is that the basic key technologies will be brought into compliance with the Commission Regulations, and the basic reference data will be accepted in the same way as in the special RIS index and European Number of Identification (ENI) ship Code.

RIS is the concept for information services in inland navigation to maintain traffic and transport management in internal shipping. In 1998, the European Union started developing the concept of River Information Services in a research environment. The potential of RIS to improve the position of inland navigation within the transport chain has been recognized by international organizations including the United Nations Economic Commission for Europe (UNECE), the Central Commission for the Navigation of the Rhine (CCNR), the Danube Commission and Permanent International Association of Navigation Congresses (PIANC). The RIS concept has been developed and detailed in the European research projects Inland Navigation Demonstrator for River Information Services (INDRIS) and Consortium Operational Management Platform River Information Services (COMPRIS) in the period from 1998 to 2005 in the Growth Programmed of the European Commission. These projects led to the adoption of the RIS concept in the Rhine and Danube countries [1].

2. Research

The INDRIS project has efficiently illustrated the technical value of the RIS concept and many of its features. The progress of INDRIS led to the launch of the COMPRIS project. This research project was the result of collaboration between 44 public and private partners from the Danube and the Rhine countries engaged in internal shipping even outside the European Union. Several organizations from Ukraine participated in the COMPRIS project.

The COMPRIS project was the last stage in the life cycle of the development of the RIS concept and can be considered as the last step towards the implementation of River Information Services at the European level. After the conclusion of the project, the market was introduced through the project in a position to offer its solutions and services based on and using proven concepts and specified technical standards.

COMPRIS also served as the basis for the formalization by the European Commission in 2005 of river information services in the RIS directive.

Main accomplishments of the research period of RIS were:
1. Developing of the basis for European cooperation on the implementation of River Information Services and RIS technical standards;
2. The developing of more user-oriented applications, not only for Vessel Traffic Management and safety of the vessels, but also oriented to additional services for the transport industry;
3. AIS transponders in accordance with IMO standards can be used in IWW, which contributes to safe navigation. They are especially useful in areas of mixed maritime and inland shipping, areas with high shipping density and areas with special navigational difficulties;
4. Inland ECDIS has proved to be a very strong platform for a number of tactical and strategic adaptations;
5. Intellectual coding of Notices for Skippers has led to the fact that National notifications for navigators have been transferred to the European level, independent of the languages of the EU Member States, Russia and Serbia;
6. Electronic Reporting has been successful in order to avoid confusion when transmitting transport data, especially during transporting dangerous goods.

The RIS directive contains binding rules for the authorities on the implementation of RIS services according to agreed technical standards. These standards are formalized as technical Commission Regulations annexed to the RIS directive. Since 2000 RIS Expert Groups have played a major role in the development of these technical standards. The RIS Expert Groups were international technical platforms ensuring the harmonized development and maintenance of RIS standards. The RIS Expert Groups acted as advisory bodies of institutions like the European Commission, the Central Commission for Navigation on the Rhine, the Danube Commission and United Nations Economic Commission for Europe on RIS standardization processes. The standards for the RIS key technologies Inland ECDIS, Notice to Skippers, Vessel Tracking and Tracing and Electronic Reporting International were formally accepted by the CCNR and UNECE and through the UNECE by the Danube Commission. The RIS expert groups are since 2020 working and giving their advice under the umbrella of CESNI [2].

The RIS Framework directive contains next responsibilities for the electronic exchange of information regarding navigation and voyage planning on IWW with potential users of RIS:
1. The waterway authorities shall supply IWW of class Va and higher in compliance with the Classification of European Inland Waterways, Electronic Navigational Charts (ENCs) suitable for navigational purposes and appointed in the Commission Regulation on inland ECDIS;
2. Provided that ship communications are required in accordance with national or international regulations, the competent authorities should be able to receive electronic ship communications of required data from ships in standard manner, as defined in the Commission Regulation on Electronic Reporting;
3. In the case of cross-border transport, information provided through Electronic Reporting shall be transmitted to the competent authorities of the neighboring state, and any such transfer must be completed before the ships arrive at the border;
4. The waterway authorities are engaged to supply NiS in standard form encoded and downloadable messages in accordance with the Commission Regulation on Notices to Skippers. The standardized report shall contain at least the information essential for safe navigation;
5. When the waterway authorities are intending to implement means for tracking and tracing of ships, it should be done in accordance with the Commission Regulation on VTT which indicates AIS version for inland navigation;
6. The competent authorities of Member States should establish RIS centers in accordance with regional needs. All Member States should also designate a national competent authority for RIS.

As can be read from the aforementioned obligations the RIS directive sets out only the requirements for water transport authorities of the Member States. The Member States shall stimulate the potential RIS users like navigators, shippers and owners to use the services provided on the IWW, however, it is not necessary to use these services on the basis of the RIS directive.

The key technologies required to provide various services are identified and described in details in the RIS guidelines. The key technologies consist of:
- Inland ECDIS;
- Vessel Tracking and Tracing;
- Notices to Skippers;
- Electronic reporting.

The relation between RIS services and key RIS technologies and theirs using with RIS Index is shown in Fig. 1.

Fig. 1 Relation between RIS services and RIS key technologies
The RIS index is important in ENCs creating and publishing of Notices to Skippers, and it is the basis for traffic management applications such as voyage planning and ETA predicting. The RIS Index is part of the Commission’s Regulation for Notices to Skippers and will most likely be included as a mandatory requirement in the next edition of the RIS directive. The RIS Index combines key RIS technologies, as shown in Fig. 2.

![Fig. 2 RIS key technologies and reference data](image)

The RIS Index is the unifying link for all four RIS standards. For example, Fig. 3 and Fig. 4 (4a) show how information is distributed from one source NtS or ERI to others with the obligatory display of its content on Inland ECDIS.

![Fig. 3 The procedure for converting and disseminating information transmitted in the RIS ERI standard using the RIS Index and displaying it on the ENC](image)

![Fig. 4 The procedure for converting and disseminating information transmitted in the RIS NtS standard using the RIS Index and displaying it on the ENC](image)
In case of vessel’s deviation from the fairway axis by a distance exceeding the permissible value, warning in the form of an audio signal will be received on the ENC, also as well as in this form as shown in Fig. 5.

In cases of using coastal AIS AtoNs for fencing fairway, the RIS index allows the ENC to obtain a visual image of the fairway width in accordance with the indications obtained from level posts (Fig. 6).
In Fig. 7 shown a diagram in which the process of obtaining the RIS index and the possibility of its use in modeling the dynamics of the bottom relief taking into account considering fluctuations in water level.

![Diagram of RIS Index formation](image)

**Fig. 7 Formation of a dynamic RIS Index for predicting bottom relief motion**

### 3. Conclusions

In order to harmoniously introduce RIS into the pan-European system, Ukraine needs to develop and conduct RIS indexing of all RIS objects in the near future, both on the Dnieper and the Danube.

The introduction of the RIS index implies a number of advantages that can improve the safety and efficiency of shipping, in particular:
- Visual display in the information block of the inland ECDIS standard in the content of messages sent using other frameworks;
- Simulation of a dynamic ENC, which allows predicting the position of isobars in real time and determining the channel width for the passage of the vessel;
- Settlement of ETA and Fairway Information System for the duration of the proposed voyage.

Using of the RIS index involves identifying a number of concerned parties (consumers) in obtaining the proposed services. For example, skippers, logistics centers, customs and border services, sea and river administrations, etc.

Problems that arise as a result of RIS indexing:
- Limited ability to obtain reliable information at some private property;
- The nature of relations between enterprises responsible on the one hand for the operation of RIS (Delta Pilot), and on the other hand for the issuance of charts in the Inland ECDIS standard (State Hydrography).

### References


Assessment of Railway Development in Baltic Sea Region

G. Vaičiūnas

Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, E-mail: gediminas.vaiciunas@vgtu.lt

Abstract

The author of the article presents a methodology for estimating the development of railways in a country relative to other countries based on the ratio of rail length in the country to GDP, the area of the country and the population. The methodology is illustrated by the example of a railway from Amsterdam to Tallinn.

KEY WORDS: the development of railways, GDP, area, population, ranking

1. Introduction – Literature Review

When developing the global railway network, the question of which countries need to encourage the expansion of the rail network is often encountered. Researchers offer various research methodologies related to the development of the rail network. The author of this article has previously addressed similar issues. He has written several articles examining the significance of the railway lines being built for the countries [1, 2]. One of the author's main insights is that the smaller the country, the greater the importance of railways. It is important to see similar works by other authors on these issues.

The literature deals with research on the relationship between the performance of road and rail freight transport and transport infrastructure in EU countries [3]. The authors of the article examined the relationship between transport performance and transport infrastructure by correlation and regression analyses. Research has shown that the strength of the relationship between transport infrastructure and transport performance is different for states.

The article examines the relationship between public investment in infrastructure in India and regional incomes and whether the character of this relationship is affected both by the nature of investment and the level of socio-economic development of the different regions [4]. The possibility of using the regional distribution of public investment as a policy instrument to reduce regional disparities is evaluated, with the analysis demonstrating that while there were prospects of concentrating on the varying forms of infrastructure in different categories of states at earlier points in time, the current situation calls for each region receiving investment in all of the different forms of infrastructure.

Another article presents the calculation of weights determining the impact of particular socio-economic factors on the volume of rail passenger transport. For this purpose the Pearson's linear correlation coefficient was used, which allowed to obtain initial values of weights [5]. Similar studies are being carried out in African and Asian regions [6, 7].

There are strong dependencies as well as strong independent relationships between the transport infrastructure and transport performance [8]. The development of railway clusters is also important. clusters of rail transport and logistics services are considered to be promising and can provide significant added value in terms of management, operational efficiency, collaboration and communications development, marketing and other [9, 10].

A research review concludes that it is expedient to create a methodology for estimating the development of railways in a country relative to other countries based on the ratio of rail length in the country to GDP, the area of the country and the population. But doing so means methodically, therefore, the research methodology must first be developed.

2. Research Methodology

The first step in the study is the comparison of economic and social indicators in the countries (the rail length in the country to GDP, the area of the country and the population.). To this end, graphs of relevant indicators are drawn up and interim conclusions are drawn from them. the values of the indicators are then used to calculate the ratio of rail length to other indicators:

$$ r_j = \frac{L_j}{x_{ij}}, $$

where $L_j$ – the rail length in the country $j$, $x_{ij}$ – indicator $i$ in country $j$.

Country rankings are computed, with the aim of making comparisons between the indicators more explicit (provided that the sum of the ratings for all countries equals 1). The ranking of every country is calculated according to the formula:
where \( R_j \) – the ranking of \( j \) country according to parameter \( i \), \( r_{ij} \) – a relative indicator of parameter \( i \) in country \( j \).

The number of indicators per country depends on the number of indicators considered. In order to determine the specific level of rail development in a country, indicators need to be aggregated by country. This can be done by arithmetic mean:

\[
R_j = \frac{\sum_{i=1}^{n} r_{ij}}{n},
\]

where \( n \) – the number of indicators.

This can also be done by the geometric mean principle:

\[
R_j = \prod_{i=1}^{n} r_{ij}.
\]

The indicators summarized in formulas (3) and (4) give an indication of the relative development of the railways in the countries.

The developed methodology needs to be illustrated with an example. A suitable example is a railway from Amsterdam to Tallinn. The relevance of this railroad can be understood by examining Fig. 1 and its commentary. These are presented in the following section of the article.

3. The Example of Realization Methodology

A new railway line „RailBaltica“ is under construction with the aim of improving the connectivity of the countries on the eastern coast of the Baltic Sea with central Europe. This railway line will pass through countries: Estonia, Latvia, Lithuania and Poland. From Warsaw this railway line will connect to the Moscow- Warsaw -Berlin-Amsterdam railway (see Fig. 1 [11]).

![Fig. 1 The railway from Amsterdam to Tallinn](image)

The emergence of a railway line from Amsterdam to Tallinn creates the need to assess the development of railways in the countries through which the railway passes. The estimating of the development of railways in a country relative to other countries is realised based on the ratio of rail length in the country to GDP, the area of the country and the population. Indicators of countries (over which the Amsterdam railway runs Tallinn) are shown in Table 1 [12-15].

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Countries</th>
<th>EST</th>
<th>LV</th>
<th>LT</th>
<th>PL</th>
<th>DE</th>
<th>BE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP, billion dollars</td>
<td></td>
<td>47,306</td>
<td>60,73</td>
<td>102</td>
<td>1287</td>
<td>4444</td>
<td>550</td>
</tr>
<tr>
<td>Population, in million</td>
<td></td>
<td>1,305</td>
<td>1,934</td>
<td>2,791</td>
<td>38,43</td>
<td>83</td>
<td>11,4</td>
</tr>
<tr>
<td>Country area sq. m. km</td>
<td></td>
<td>44226</td>
<td>64589</td>
<td>65300</td>
<td>312696</td>
<td>357112</td>
<td>30528</td>
</tr>
<tr>
<td>Railway length in the country, km</td>
<td></td>
<td>1018</td>
<td>1934</td>
<td>1767</td>
<td>23420</td>
<td>40826</td>
<td>3518</td>
</tr>
</tbody>
</table>
For a better understanding of the data in Table 1, it can be analyzed graphically. First, indicators such as the length of the railways in the countries, area, population, GDP of countries. The length of the railways in the countries is shown in Fig. 2.

Looking at Fig. 2, it is hardly surprising to see that the largest rail network is in Germany and the smallest in Estonia. The larger countries have correspondingly longer rail networks. Indicators such as GDP, area, population, determine the size of a country. It is worth reviewing these indicators. GDP of countries (in billion dollars) is shown in Fig. 3.

![Fig. 2 The length of the railways in the countries](image)

![Fig. 3 GDP of countries, billion dollars](image)

The railway lengths of the countries concerned are similarly proportional to the national GDPs of the countries concerned. You can see that in Fig. 3. The country area is shown in Fig. 4.

![Fig. 4 Country area sq. M. km](image)

Countries with a larger area have a larger GDP and a longer rail network respectively. Such a conclusion can be drawn from the Fig. 4 diagram. The population of countries is shown in Fig. 5.

From the graphs of Figs. 3-5, it can be tentatively concluded that the development of railways in countries is directly proportional to indicators such as the GDP of a country, the area and population. On the other hand, it is a very hasty conclusion. The author of the article does not dispute the principle aspect of this conclusion. However, the author points out that if the proportions of rail lengths and other indicators were the same in the countries, the ratio of the respective indicators should be the same in the countries (for example, the ratio of rail length to GDP should be the same in the countries). The ratio of rail length to GDP is shown in Fig. 6 (is calculated according to the formula (1)).
The graph in Fig. 6 shows that countries with lower GDP have a better rail length to GDP ratio. The reason for this is the minority of GDP. The ratio of railway length to area of the country is shown in Fig. 7.

In Fig. 7, the charts again lead the major countries. The greater length of the country's railways also leads to a better ratio of rail lengths to the area of the country. The ratio of rail length to population is shown in Fig. 8.

The country's ratio of rail length to population is higher in countries with a lower population. By relative ratios (the ratio of rail length in the country to GDP, to the area of the country, to the population of the country) for each indicator, it is possible to calculate the weighted share of that relative indicator in the respective country. The ranking of every country is calculated according to the formula (2). The ranking of a country in terms of rail length to GDP ratio is shown in Fig. 9.
The diagrams in Fig. 9 show the same pattern as in Fig. 5, except that the sum of all values here equals 1. The ranking of a country in terms of rail length to GDP ratio is shown in Fig. 10.

The diagrams in Fig. 10 show the same pattern as in Fig. 7, only the sum of all values here equals 1. Country ranking by rail density is shown in Fig. 11.
The diagram in Fig. 11, like the diagram in Fig. 6, shows that the greater length of the country’s railways also leads to a better ratio of rail lengths to the area of the country. The results of the diagrams in Figs. 9-11 can be summarized by arithmetic mean or geometric mean. The summarized ranking of countries’ railways development in the arithmetic mean is shown in the Fig. 12 (is calculated according to the formula (3)).

Fig. 12 The ranking of countries railways development is summarized in the arithmetic mean

Ranking of country rail development summarized by Geometric Mean is shown in Fig. 13.

Fig. 13 Ranking of country rail development summarized by Geometric Mean

The diagrams in Figs. 12 and 13 can be used to evaluate the development of the railways in relation to other indicators of development in the country. In this respect, railways are more developed in Germany, Poland and Latvia, but less developed in Lithuania, Estonia and Belgium. There is no significant difference between the country rankings by the arithmetic mean method and the geometric mean method; there is no principle difference in the graphs of Figs. 12 and 13.

4. Conclusions

1. The indicator of the development of the railway network is not only the length or density of railways in the country, but also the ratio of the length of railways to the GDP of the country and the ratio of the population.
2. There is a possibility to methodically estimate the relative development of the railways in developing countries based on their GDP, area and population. The author of the article proved this by providing an example of methodology.
3. By relative the ratio of rail length in the country to GDP, to the area of the country, to the population of the country for each indicator, it is possible to calculate the weighted share of that relative indicator in the respective country. Thereby assessing the relative development of railways in the countries in relation to the development of other areas.

References
2. Vaičiūnas, G.; Steišūnas, S. 2017. Investigation of priority directions of rail baltica extension from Warsaw,


Aerodynamic Optimization of the Wing Trailing Edge Flap

M. Lendraitis¹, V. Lukoševičius², R. Makaras³

¹Kaunas University of Technology, Studentų g. 56, Kaunas 51424, Lithuania, E-mail: martynas.lendraitis@ktu.lt
²Kaunas University of Technology, Studentų g. 56, Kaunas 51424, Lithuania, E-mail: vaidas.lukosevicius@ktu.lt
³Kaunas University of Technology, Studentų g. 56, Kaunas 51424, Lithuania, E-mail: rolandas.makaras@ktu.lt

Abstract

The paper presents a developed algorithm and its outcomes for the aerodynamic optimization of the wing section trailing edge flap. The optimization process is localized at a defined distance from the trailing edge. Shape change is described as B-spline with control points controlled by the genetic algorithm. The task of the algorithm is to reach the best objective function value at a given flap deflection, resulting in higher flap efficiency. The algorithm objective function uses the XFOIL code for fast performance evaluation. The algorithm is tested by optimizing the airfoil NACA 2412 flap at 70% location with a deflection angle of 5° and 10°. Aerodynamic performance is evaluated and compared with the XFOIL and the CFD k-ε flow model results. The optimized flap performance results are compared with a plain flap, showing a possible flap performance gain of at least 29%, as predicted by the k-ε flow model. Also, the change in the lift coefficient is about 52% higher than the plain flap at the same flap deflection. The developed algorithm is suitable for optimizing flap shape and can be used in morphing aircraft wing design.

1. Introduction

The evolving field of morphing aircrafts has raised the interest in airfoil optimization, which is relevant to the wing structure [1-3]. The airfoil shape must be designed in such a way, that the morphing structure would be capable of achieving it. The easiest way to do this is to construct a wing structure, which would have the ability to morph. Then - test the resultant shape for any possible aerodynamic benefits. This method does not always produce positive results and often requires a significant amount of effort. By defining the aerodynamic shape first, more favorable results may be achieved. Thus, software which can produce such a shape is required. Results could be used for structural optimization as a wing outer surface objective.

Airfoil optimization itself is a difficult task, this difficulty rises from a number of variables contributing to overall airfoil performance [4]. Novel approaches based on Lattice Boltzmann and the adjoint method, together with different types of evolutionary algorithms, have been proposed by the researchers, suggesting different ways of approach to the same problem [5, 6].

The airfoil optimization process is a time-consuming task. Most of the computing time is used for airfoil performance calculation. Using most commercially available CFD solvers, the computer can take several hours or even days to calculate a solution for a given problem [7]. Panel methods offer much faster results with a reasonably high level of accuracy [8]. Fast calculation speed allows the evaluation of a large amount of possible airfoil designs, which are essential when using evolutionary algorithms. One of the most popular panel method software XFOIL [9] is shown to be robust and produce good results, hence it being used by several researchers [10, 11].

Most of airfoil optimization in literature is performed on a whole airfoil shape. Implementing a morphing section only at the rear of the airfoil reduces the overall optimization and structural complexity. This simplifies to an already existing wing component (flap) optimization. On a plain flap the rear portion of airfoil rotates on a simple hinge, mounted at the front of the flap [12], this results in a sharp curvature change at the surface near the rotation axes, which reduces aerodynamic efficiency. The optimized shape of the flap is much smoother and favorable in achieving higher efficiency.

Optimizing only the trailing edge is a lot easier because fewer control variables are present. Still, it requires having some structural constrains to reduce possible outcomes of unfeasible designs, which are not possible in the use of existing morphing structure implementation. When designing a morphing flap, a different shape could be defined for multiple deflection angle and flow condition. The robust optimization algorithm is needed to evaluate all these possible conditions, to generate a set of flap profiles which can later be used for wing structure formation.

2. Optimization Algorithm

The airfoil flap optimization algorithm is developed using MATLAB software [13] and using XFOIL as the aerodynamic calculation tool for an objective function evaluation. Flap performance is greatly dependent on the hinge position along the chord. The developed algorithm allows the choice of location at which the optimization can occur (Fig. 1). A smaller flap requires less control points, thus reducing the optimization complexity and time to convergence.
The front airfoil section is left unchanged throughout the optimization process.

Fig. 1 Airfoil with a defined variable section for optimization

To easily control the trailing edge geometry during optimization a B-Spline curve was used. The curve is defined as a linear combination of control points $p_i$ and B-spline basis function $N_{i,k}(t)$ given by: [14].

$$r(t)=\sum_{i=0}^{n}p_i N_{i,k}(t), \quad n \geq k-1, \quad t \in [t_{i-1}, t_{i+1}],$$  \hspace{1cm} (1)$$

where $t$ – nodes.

The curve’s shape can be easily changed by altering the position of the control points, the algorithm forms two curves at the upper and lower trailing edge surfaces. One of the curve’s end is fixed at the start of the variable section. The end of the curves could be fixed at the desired vertical $y$ position, imitating user defined flap deflection, or it could be left to move freely. At the trailing edge, both curves are separated from each other by a defined distance, to ensure trailing edge thickness.

The control point’s location which is closest to the variable section can only move along the tangential line, generated from the last two coordinate points of the fixed airfoil section. This allows the creation of a smooth curve transition between the sections.

Fig. 2 Airfoil variable section with specified control points

The control point location is defined by only one variable. The tangential position is then expressed by the following equation:

$$P_y = P_x \left( \frac{P_{y2} - P_{y1}}{P_{x2} - P_{x1}} \right) + S_y,$$  \hspace{1cm} (2)$$

where $P_x$ – control point location in the x axis; $P_y$ – control point location in the y axis; $S_y$ – position of the beginning of the morphing section on the y axis.

When the flap deflection is set, the length of the chord becomes slightly shorter. The same happens to a morphing wing, but in a slightly different manner. The way this happens is set by the morphing structure. We assume, that the upper surface is bent while the lower is pulled. That means, that the length of the upper surface doesn’t change, no matter the deflection angle. This assumption is applied in the algorithm. When the flap is not extended, the length of the upper surface is calculated. When the deflection is set, the same calculation happens, but this time the curve is cut at the length of the previous measurement, forming a new x location of the trailing edge.

The shape of the trailing edge is altered by changing the location of B-spline control points. To prevent unrealistic airfoils, the design space is defined with two-dimensional min/max boundaries for every control point. Control points are manipulated by the optimizer. At every iteration, a new set of coordinates inside the design space are generated, from which a new flap is formed. To perform an aerodynamic calculation, a set of airfoil coordinates must be formed. Therefore, a formed curve must be split into coordinates. Then those coordinates are joined with fixed airfoil coordinates, forming a new airfoil data set. The airfoil is then executed by performing an XFOIL calculation with predefined boundary conditions.

The optimization of one operating point is never feasible, because of the tendency of generating a spike on the
airfoil drag polar [4]. This makes the optimizer converge faster, but the generated airfoil works well only at that operating point, making it unfeasible at every other. To overcome this, a multi-point optimization is performed, with a minimum of four points.

The objective function can have any desired structure, which is defined by the optimization goal. The optimization outcomes will greatly depend on the chosen objective function. For the sake of efficiency, a simple objective function with weighted operating points is defined:

\[ T = \left( \frac{\sum_{i=1}^{n} a_i (c_{i,L}/c_{i,D})}{n} \right) + \chi ; \ n \geq 4. \]  

(3)

This function is a weighted average of lift and drag coefficients at multiple operating points. The optimizer’s goal is to find the minimum value of this function.

Every optimization point is weighted with the corresponding coefficient \( a_i \). This allows the generation of a more defined and smooth lift curve. The optimization can be set by defining the angle of attack or lift coefficient range as the operating points. When \( c_{i,L} \) is fixed, only \( c_{i,D} \) is altered to reduce objective function. This could raise a problem of unconvergence, when defined \( c_{i,L} \) can’t be achieved by the generated airfoil. Therefore, the optimization on a specified angle of attack is more reliable and because of this is used in this optimization.

One of the structural constraints is the minimum trailing edge angle, which is a part of the objective function, which prefers airfoil with a higher trailing edge angle.

\[ \chi = \begin{cases} 
    d - \theta, & \theta \leq \theta_p \\
    0, & \theta > \theta_p 
\end{cases} \]

(4)

where \( d \) – penalty value coefficient; \( \theta \) – trailing edge angle; \( \theta_p \) – minimum trailing edge angle; \( \chi \) – penalty value.

When the trailing edge angle is smaller than defined, a proportionally increasing penalty is applied, which adds to the final objective function value.

Airfoil optimization can be approached using basic population-based, metaheuristic algorithms, also called evolutionary algorithms. Evolutionary algorithms perform well when searching for the approximate solution for all types of engineering problems, even when the objective function is discontinuous, highly nonlinear or stochastic [15]. Previously they were also used in airfoil optimization with good results [16, 17].

The genetic algorithm from MATLAB global optimization toolbox [18] was used. During optimization, the algorithm modifies the control point coordinates to change the shape of the flap. At first, the primary generation of flaps are formed randomly or according to the already evaluated designs from the previous calculation. First, the algorithm selects individuals from the current population (according to the objective function and optimization settings) and uses them as parents to produce the children for the next generation.

Over the consecutive generations, the flap population evolves toward an optimal solution and Algorithm stops when the stopping criteria is met [19].

3. Aerodynamic Calculation Validation

Most of the aerodynamic calculations require some form of validation to ensure the accuracy of the calculated output. Literature suggests, that both the XFOIL and the CFD codes have good correlation with experimental results [11]. Still, it greatly varies with change in the Reynolds number, flow condition and shape. For CFD calculations, an accurate flow model must be selected [20].

To determine possible errors in the calculations, experimental results are compared with XFOIL and CFD calculations performed in ANSYS Fluent software. NACA 2412 airfoil was chosen for the analyses. The experimental data at 3.1M Reynolds number for this airfoil is presented in NACA report [21].

After several evaluation runs with different flow models, the k-kl-\( \omega \) flow model was selected, which showed results closest to the experimental data.

The calculation results are shown in Figs. 3 and 4. Both XFOIL and k-kl-\( \omega \) models show a good agreement with experimental results on lift coefficient (Fig. 3). Only small deviations are present. Unfortunately, the drag results are slightly different. XFOIL tends to overestimate drag coefficient by about \( 9 \times 10^{-4} \) across the drag polar. (Fig. 4). The k-kl-\( \omega \) flow model underestimates drag coefficient by about \( 1.6 \times 10^{-3} \). In both cases the shape of the drag polar is simulated almost identically. Results suggest, that both models can predict airfoil performance with reasonable accuracy. Still, caution should be taken when addressing the drag coefficient. To draw a conclusion, both calculations should be performed.
4. Optimization Algorithm Analysis

To evaluate algorithm performance, airfoil NACA 2412 was used for the trailing edge flap optimization. The variable section was set to start at 70% of the chord. Aerodynamic calculations were performed at the Reynolds number of 3.1M. Optimization was performed at the angle of attack, ranging from -1 to 4 degrees, with a total of 6 operating points. Three B-spline control points were used on every trailing edge surface with a total of six points. The trailing edge location on the y axis were fixed at locations corresponding to the flap deflection angle of 5 and 10 degrees with hinge position at 70% of the chord.

To consider the optimization as “fast”, the maximum target time was set as 90 min. After evaluating the time required for the objective function to generate results, a preliminary population size was defined. After several optimization runs, it was decided, that best results with given boundaries could be achieved by using a population size of 65 individuals. The evaluation also showed, that after about 50 generations, the change of the objective function value was not significant. To overcome the time constrain, maximum generations were set to 60. The function tolerance was set to 0.03. The recombination value was set to 0.8 and the elite individual count to 6.

With these settings, a typical run lasts less than 90 min. on a desktop computer with 4 core 2.6 GHz processor. The geometry of the optimized and plain flaps can be seen in Fig. 5. At a deflection angle of 5°, the geometry differences are minimal. At a deflection of 10° the difference is significant and well defined.

![Fig. 5 Plain and optimized flap geometry comparison. a – 5°; b – 10° deflection](image)

Fig. 5 Plain and optimized flap geometry comparison. a – 5°; b – 10° deflection

![Fig. 6 Drag polar of NACA 2412 airfoil with plain and optimized (opt) flaps at a deflection of 5 degrees generated by XFOIL and k-kl-ω flow model](image)

Fig. 6 Drag polar of NACA 2412 airfoil with plain and optimized (opt) flaps at a deflection of 5 degrees generated by XFOIL and k-kl-ω flow model

![Fig. 7 Drag polar of NACA 2412 airfoil with plain and optimized (opt) flaps at a deflection of 10 degrees generated by XFOIL and k-kl-ω flow model](image)

Fig. 7 Drag polar of NACA 2412 airfoil with plain and optimized (opt) flaps at a deflection of 10 degrees generated by XFOIL and k-kl-ω flow model
Before evaluating the overall performance of the flap, airfoil performance was examined. Drag polars in an angle of attack ranging from -5 to 14 were calculated for the optimized and plain flaps (Figs. 6 and 7). The positive effect is clearly seen in both graphs. Even though the XFOIL and k-kl-ω flow model results slightly differ because of different drag estimation, both show similar improvements to the drag polar.

The lift to drag coefficient ratios have improved on both airfoils with optimized flaps, especially the one with a deflection of 5 degrees. It is clear from figure 8, that an improvement of up to 12 units is seen on the angle of attack ranged from -5 to 5 degrees on the k-kl-ω flow model prediction, and from -5 to 11 on the XFOIL prediction. This greatly surpasses the set optimization operating point range, which was set from -1 to 4.

At the deflection angle of 10 degrees, the lift to drag coefficient improvement is seen in a shorter range from -5 to 4 degrees. The improvement is the highest at small angles of attack and spikes up to 40 units by XFOIL’s prediction. Unfortunately, the change at higher angles of attack is much smaller and at 3° it is less than 5 units. After about 4° there is not much change in c_l/c_d in comparison to the plain flap. The k-kl-ω flow model predicts slightly a poorer performance at that range.

![Fig. 8 Lift to drag coefficient ratio variation through the angle of attack range of the NACA 2412 airfoil with plain and optimized (opt) flaps at a deflection of 5 degrees generated by the XFOIL and k-kl-ω flow models](image)

![Fig. 9 Lift to drag coefficient ratio variation through the angle of attack range of the NACA 2412 airfoil with a plain and optimized (opt) flap at a deflection of 10 degrees generated by the XFOIL and k-kl-ω flow models](image)

Figs. 10 and 11 show the changes in lift coefficient Δc_l in comparison to the non-flapped NACA 2412 airfoil. The advantage is clearly seen on both optimized flaps for all angles of attack. The k-kl-ω flow model shows a larger change of lift compared with the XFOIL calculation. The greatest agreement between the calculation methods is seen at lower angles of attack, where the optimization occurs. The formed curvature is responsible for achieving the higher lift coefficient at the same angle of attack.

![Fig. 10 Change in lift coefficient through the angle of attack range of the NACA 2412 airfoil with plain and optimized (opt) flaps at a deflection of 5 degrees generated by the XFOIL and k-kl-ω flow models](image)

![Fig. 11 Change in lift coefficient through the angle of attack range of the NACA 2412 airfoil with plain and optimized (opt) flaps at a deflection of 10 degrees generated by the XFOIL and k-kl-ω flow models](image)
The airfoil with flap performance evaluation only gives a short impression of the actual effects of the flap. For a full performance evaluation, the change in lift coefficient versus the deflection angle is important. Because the two shapes were optimized at a certain deflection and their performance was calculated, it is safe to assume, that the designed morphing structure would achieve these shapes at these deflections. Therefore, to evaluate the optimized flap performance at a certain deflection, the interpolation between the designs was done. For the evaluation, an angle for attack of 3° was chosen, which made a moderate improvement in the optimized range.

![Fig. 12 Change in the lift coefficient versus the flap deflection angle at a 3° angle of attack](image)

![Fig. 13 Performance versus flap deflection angle at 3° angle of attack](image)

The optimized flap has a greater change in lift coefficient for every deflection angle compared with a plain flap (Fig. 12). It is clear, that the deflection required to achieve the same lift coefficient is significantly smaller. By the prediction of XFOIL, the flap needs to be deflected 3° less than the plain flap to have the same lifting effect.

The ratio of changes in the lift and drag coefficient versus the deflection angle (Fig. 13) shows the change in performance. At every deflection, the performance is significantly greater. The greatest performance gain is at a deflection angle of 5 degrees, where XFOIL suggests almost 47% of performance gain. The k-kl-ω flow model predicts a smaller gain of 29%. By looking at the lift to drag coefficient ratio graphs (fig 8 and 9), the biggest flap performance improvements should be achieved at angles smaller than 3°.

3. Conclusions

The developed algorithm is well suited for optimizing flap geometry at multiple operating points. The algorithm can produce optimized flap geometry in less than 90 min on a regular desktop computer. The optimization of the NACA 2412 airfoil flap showed good results by increasing the lift to drag coefficient ratio at the designated operating points, while keeping almost the same performance at the non-specified angles of attack. Evaluating the overall optimized flap performance at 3° angle of attack, the optimized flap produced lift coefficient change was 52% higher that the plain flap at all the deflection angles. Flap performance increased by about 12-29%. The optimization outcomes were proven to be reliable with two different aerodynamic calculation methods at moderate Reynolds numbers. Multiple optimized shapes could be formed for the same flap and applied on morphing the aircraft structure to enhance its performance through the flight envelope.

Acknowledgment

This research was supported by the Research, Development and Innovation Fund of Kaunas University of Technology (PP32/1814).

References

Safety Recommendations as a Method of Strengthening Resilience of the Railway System

P. Smoczyński¹, A. Gill², A. Kadziński³

¹Poznan University of Technology, Pl. M. Skłodowskiej-Curie 5; 60-965 Poznań, Poland, E-mail: piotr.smoczynski@put.poznan.pl
²Poznan University of Technology, Pl. M. Skłodowskiej-Curie 5; 60-965 Poznań, Poland, E-mail: adrian.gill@put.poznan.pl
³Poznan University of Technology, Pl. M. Skłodowskiej-Curie 5; 60-965 Poznań, Poland, E-mail: adam.kadzinski@put.poznan.pl

Abstract

Resilience engineering is a relatively new scientific approach to the subject of the safety of complex sociotechnical systems. Despite intensive research, covering many aspects of human activity, resilience is still primarily defined by the effects it brings. A particular problem is the development of a catalogue of practical resilience-building measures that could be used by people involved in the work of the studied systems. One of the groups with a potentially significant impact on resilience building are people responsible for formulating conclusions of investigations of adverse events. This study aims to determine whether and how the formulation of investigation conclusions can help increase the resilience of the railway system. To this end, safety recommendations issued by the Polish National Investigation Body following railway events in 2007–2016 have been analysed. On this basis, comments were made on the preparation of recommendations in a way that takes into account the need to improve the resilience of the railway system.

KEY WORDS: rail system safety; railway risk; safety engineering; accident analysis; resilience engineering

1. Introduction

Investigating the causes of incidents and accidents is a very important way to improve the safety of a railway system. For many years of the development of railways this was a fundamental way of developing the regulations that are still in force today, which are often said to be written in blood. However, with the increasing speed of progress, it became impossible to understand the way technical systems work and consequently, to manage safety – in a purely intuitive way.

In response to new requirements, there have been ongoing works since the 1890s providing theoretical models of the operation of technical systems. One of the first models describing scenarios of accidents was the so-called domino model proposed by Heinrich [13]. The following years brought the development of new accident models [6] as well as tools such as the fault tree analysis and the FMEA analysis. Accidents have begun to be treated as input to hazard identification with a “backward” approach [3, 10], which is a part of the risk management process.

Until the beginning of the 21st century, it was a common belief that by eliminating the sources of identified hazards, using both historical data and many methods of systematic search in the domains of analysis, the number of accidents could be effectively reduced. However, this is in contrast with Hollnagel’s theory of functional resonance and so-called Safety-II [14]. These assume that in today’s complex sociotechnical systems, it is often impossible to pinpoint the specific causes of events; they are rather a consequence of the “resonance” of many mutually independent and not clearly defined phenomena occurring in a given system.

A similar view is expressed, for example, by Dekker, who writes that the real cause of accidents in complex systems is their daily functioning, marked by bending the rules to accomplish the entrusted task [7]. Hale [12] proposes to depart from the rigid rules created at higher organisational levels and create them locally, taking into account the experience of employees. Grote even points out that increasing uncertainty at the “sharp” (executive) end of complex systems leads to increased safety [11].

All research on the need for flexibility in organising sociotechnical systems is part of a relatively new trend of research called resilience engineering. Resilience is understood, among others, as the ability of a system to expand its capabilities in the face of events not previously anticipated [21]. Costella et al. [5] list four features of resilient systems:

1. Top management commitment;
2. Increasing flexibility;
3. Learning from incidents and normal work;
4. Awareness of the system’s status.

The purpose of this article is to analyse the reports on the causes of the most significant railway accidents in Poland in 2007–2016, to determine whether and how recommendations formulated in them can improve the resilience of a railway system. Section 2 discusses the legal basis for investigating the causes of adverse events on European railways.
Section 3 contains the source material and the methodology of data analysis used. Section 4 presents the results of the analysis, which are discussed in Section 5 in relation to the resilience of the railway system. Section 6 contains conclusions on the formulation of safety recommendations in the context of increasing the resilience of the railway system.

2. Legal Basis for Railway Accident Investigations

In all Member States of the European Union there are National Investigation Bodies (NIB), set up in the process of transposition of the 2004 Railway Safety Directive into national law. Under these regulations, these authorities must be completely independent of infrastructure managers and railway undertakings and must employ at least one permanent member. In Poland the role of the NIB is fulfilled by the Chairman of the State Commission for Investigation of Railway Accidents, at the Ministry of Infrastructure and Construction. The commission was established in 2007.

There is a legal duty to inform the NIB of all accidents and incidents (jointly referred to as ‘events’) that have taken place on the essential part of the European railway network in a given Member State. The NIB may, within a week, decide to take over the proceedings from the accident commissions operating within the safety management systems of individual participants of the railway market. This is always the case in the event of a serious accident and also when the clarification of another type of event has, in the authority’s opinion, a significance for the railway safety in the European Union.

A serious accident is defined in the directive [8] as a collision of two trains or derailment of a train, resulting in:
- death of at least one person;
- serious injuries of at least five people;
- significant damage to rolling stock, infrastructure or environment.

In this context, “serious injuries” are injuries that require hospitalisation for at least 24 hours and “significant damage” is damage that exceeds two million euros.

The task of the NIB is to determine the cause of the incident rather than to identify the guilty party – thus the investigations are conducted regardless of the actions of other state authorities (prosecutors, police). The result of the NIB’s work is a report that should be prepared no later than one year after the occurrence of the event. It contains the so-called safety recommendations (hereinafter referred to as recommendations), which, despite their name, are compulsory orders for implementing specific procedures. Recommendations may be issued to all institutions and entities whose involvement may prevent similar occurrences in the future.

3. Materials and Methods

3.1. Characteristics of the Analysed Events

In 2007[2016, the ERAIL database (European Railway Accident Information Links) [9, 19] recorded 24 events reported by the Polish National Investigation Body (NIB). Some of them were not serious accidents according to the directive [8] they were investigated by the NIB because of their importance to the railway system. The registered events can be divided into four categories: Collisions, Derailments, Accidents at level crossings and Other events.

As a result of all reported incidents, 40 people died and 174 were seriously injured. In the analysed period, six train collisions were reported to ERAIL. Four of them occurred after a train passed a signal at danger. However, the NIB also sought systemic causes of these situations, such as fatigue caused by ineffective legal regulations concerning the working time of train drivers. Two train collisions occurred as a result of errors on the part of infrastructure managers, who directed trains to occupied tracks using the so-called substitute signal, which is normally used in the event of damage to the railway traffic control devices. One of these events, which took place in 2012 on the Sprowa-Starzyn section, led to the death of 16 and serious injuries to 61 people. This was the most serious accident in Poland in the analysed period.

Of the five reported events that resulted in the derailment of the train, two were caused by improper interpretation of light signals. The remaining three derailments resulted from the poor technical condition of the rolling stock, including, in two cases, the breakage of the wheel axle. In one case, the NIB also pointed to the negligence of maintaining the railway track.

The largest category of events analysed are accidents at level crossings, where in total 18 people were killed and 58 seriously injured. In three of the investigated events, the cause was the disregard of the traffic regulations by drivers of road vehicles: ignoring STOP signs or properly working traffic signalling. For two other events, additional circumstances were identified, such as a narrow road leading through the level crossing or the terrain, which significantly obstructed the view of oncoming trains for road vehicle drivers. Results of the investigation of causes of the remaining six events at level crossings showed errors on the part of entities operating in the railway system. Four times, there were non-compliances in the actions of the infrastructure manager. In one case, communication between the manager and the owner of a private level crossing failed. In one case, the manual barrier was not closed, as the train came unexpectedly after the driver passed a signal at danger.

Two of the reported events were classified as “other events”. In the first one, a worker of a snow removal company was hit by the train at the platform. As a result of, among others, the negligence at the stage of concluding the contract by the infrastructure manager, this person was not effectively informed about the approaching train and died in the accident. The second event involved hitting the station building by a group of improperly secured freight wagons, which led to the death of three people.
3.2. Method of Analysis of Safety Recommendations

In the preliminary stage a list of all recommendations issued by the Polish NIB was prepared. For this purpose, the data collected in the ERAIL database was used:
- the full content of final reports (in Polish);
- the contents of the recommendations contained in the “Recommendations” module of the ERAIL database (translated into English by the NIB).

Due to the quality of the translation used, which sometimes made it difficult to understand the content, the authors decided to use primarily the content of the recommendations directly from the final reports. Only in two cases, where such reports were not available, the recommendation content of the “Recommendations” module of the ERAIL database was used.

In the described way, 185 recommendations presented in [20] were gathered. This number is different from the number of records stored in the “Recommendations” module of the ERAIL database, which is 171. This is because some records in the “Recommendations” module contain several separate recommendations or, in one case, only a bulk reference to a separate text file.

The adopted principle of retaining the original content of the reports of the Polish NIB required some additional decisions. Firstly, longer recommendations – sometimes involving several independent issues, e.g. regarding safety management systems – were not divided. Secondly, in a few cases, “recommendations” which are a list of immediate actions taken after the event was also included in the analysis. In most of the reports these are described in separate subsections.

The compiled list of recommendations – issued by the Polish NIB in the years 2007–2016 in connection with the events reported to the ERAIL database – was further analysed in terms of two criteria:
- Criterion 1: Content of the recommendation;
- Criterion 2: Range of application of the recommendation.

During the analysis under Criterion 1, recommendations were assigned to the following six thematic groups:
1. Transferring responsibility for choosing a solution to an entity;
2. Enforcing increased surveillance;
3. Changing the scope and subjects of trainings;
4. Enforcing document updates;
5. Direct orders other than in groups 1–4;
6. Only informative recommendations.

These groups were identified on the basis of the analysis of the recommendation content, considering their impact on the resilience of the railway system.

The range of application of recommendations (Criterion 2) was evaluated in a binary way, regardless of the content of the recommendation. If a recommendation was addressed to one entity or its organisational unit (although its content indicated that it could also be addressed to other entities or units) the recommendation was qualified as a limited range recommendation. Otherwise, when a recommendation concerned all the entities for which it made sense, it was considered that its range of application is not limited.

4. Results of Analysis of Safety Recommendations

In the first stage of the analysis, the recommendations of the Polish NIB from 2007-2016 were assigned to previously identified thematic groups under Criterion 1. In a total of 173 cases it was possible to identify one group to which the recommendation should be qualified. A further 12 recommendations, due to their multifaceted nature, were assigned to several groups simultaneously: in ten cases to two groups, in one case to three groups and one case to four groups.

Forty recommendations (20%) required railway undertakings to consider the possibility of taking certain actions or developing a more detailed form (e.g. records PL-975, PL-5199 in [9]). In addition, the recommendations in group 1 also address clarifying or completing the railway operators’ hazard records. In most cases, recommendations of this type should be implemented in accordance with the safety management system of the infrastructure manager or railway undertaking, possibly in accordance with the internal procedures of the relevant ministry or authority.

Recommendations concerning controls and audits (thematic group 2) represent 15% of the total number of recommendations. This group includes audits of safety management systems performed by the National Safety Authority, as well as activities performed within a given entity (e.g. records PL-1214, PL-2824 in [9]). A similar percentage of the analysed recommendations, about 15%, concerned the frequency and subjects of trainings for staff working on railway system safety (thematic group 3). Almost all reports require the development of an informative bulletin about the event followed by discussion of its causes, at least among the employees of the entities that were involved in the event. Sometimes the recommendations contain detailed indications of subjects to be discussed with employees (e.g. records PL-1214, PL-2605 in [9]).

The group concerning document updates (thematic group 4) is the smallest of the thematic groupings of recommendations. This group contains recommendations regarding regulatory documents (e.g. stations’ technical regulations, internal instructions), as well as documentary evidence of the implementation of procedures (e.g. railway and road journals, employee lists).
A total of 74 recommendations, i.e. 37% of all recommendations (thematic group 5), are precise orders concerning issues other than supervision (gr. 2), trainings (gr. 3) and documentation (gr. 4). Their degree of complexity is varied. In some cases the recommendations apply to simple cleaning works, e.g. [9]: A significant part of the recommendations, however, requires more demanding actions of organisational nature (e.g. record PL-932 in [9]).

Eight of the analysed recommendations were informative (thematic group 6), without posing requirements for specific entities (e.g. records PL-575, PL-766 in [9]).

The analysis of the recommendations under Criterion 2 on the range of application of the recommendations has shown that in approximately 65% of cases, the recommendations issued by the NIB only relate to a part of the railway system. There are two types of limiting the range of application of the recommendation:

1. Limitation arising from the circumstances of the event;
2. Limitation to the national infrastructure manager.

The limitation resulting from the circumstances of the event occurs primarily in recommendations that are of an intervening nature and concern the introduction of speed limits, changes in train traffic rules, etc. This correlation is also evident in the graphs illustrating percentages of recommendations with limited range of application, broken down by event category and thematic groups of recommendations (Fig. 1).

![Graph](image)

**Fig. 1 Limitation of the range of application of safety recommendations: a – taking into account the event category; b – taking into account the thematic groups**

Based on the results shown in Fig. 1, it can be stated that the range of application is mostly limited in case of recommendations that follow atypical events and events on railway crossings, i.e. in situations where local conditions are important (e.g. the shape and type of the road leading through the level crossing). Limitations relate primarily to direct orders, as well as to document updates and supervision, and thus actions of intervention. Another group contains limitations which recommend performing certain actions by the national infrastructure manager. Due to the fact that it manages approximately 96% of the railway infrastructure in Poland, the recommendations issued to this entity may, in the opinion of the NIB, be directed at the entire railway system. Formally, however, they do not concern other managers.

5. Discussion

The resilience engineering is a relatively new scientific approach to the subject of safety of complex systems, such as the railway system. Resilience is quite well defined, but only through the effects it brings. There is still a lack of knowledge about what kind of undertakings help build resilience, or how it can be strengthened or weakened [17]. This article addresses the impact of safety recommendations – issued as a result of the investigation of the causes of the events – on the resilience of a railway system.

To this end, the recommendations issued by the Polish NIB in 2007–2016 were divided into six thematic groups. The first one (thematic group 1) contains recommendations that transfer the responsibility for choosing the solution of a problem to another entity – the railway undertaking, the infrastructure manager or a state body. From the point of view of resilience engineering, such procedures seem to be appropriate, allowing greater flexibility in the choice of measures used or discontinuing the implementation of a specific recommendation in particularly justified cases. However, with the transfer of responsibility, the NIB loses its influence on the final form of the planned actions, and such recommendations have an unclear impact on the resilience of the railway system.

Attention should also be paid to the way some recommendations are formulated. It gives the impression that the NIB presupposes that the recommendation will not be implemented. The most striking example is the recommendation from 2010 [9], addressed to all market players, for undertaking work to introduce cab signalling. In the existing legal environment, this implies the implementation of the European Train Control System (ETCS), but the key decisions are taken at the governmental level rather than within the individual entities' safety management systems.

Another identified group of recommendations was a group that included an order to increase the number of controls or audits (thematic group 2). This type of recommendations accounted for 15% of all recommendations analysed. However, their number (30) should be compared with the number of events where protocols were analysed (24). A comparison of these figures leads to the conclusion that in each of the investigations, an average of more than one recommendation concerning broadly defined surveillance was issued.
The phenomenon of increasing the number of formal controls/audits within management systems is sometimes referred to as compliance culture [15], evolving within the audit society [18]. In this context, it is pointed out that limiting violations of rules, increasing supervision and enforcing strict compliance (under penalty of disciplinary action) also have negative effects [2]:

- hindering or preventing employees from adjusting to the prevailing conditions;
- employees are less committed to understanding the nature of their work;
- it fosters situations in which documents do not reflect the reality, but meet the requirements of procedures.

The existence of negative effects does not mean that employees should not be controlled, but one must be aware, that increasing supervision may lead to weakening the system's resilience. Negative effect may also result from carrying out additional checks of the technical condition of equipment and vehicles, if this involves additional workload at the expense of performing other tasks.

Undoubtedly, conducting trainings (thematic group 3) practically always has a positive influence on improving the resilience of a system, as this increases the awareness of the risks among employees. In this category, however, there are recommendations which seem rather controversial. These are recommendations to discuss the principles of a train drivers' basic activities, such as a brake test or driving through a section with automatic block signaling. If such trainings are indeed necessary, it may indicate the potential for development of the training formula itself and changing the way teams of people function [4].

Among the analyzed recommendations, 20 ordered updates of certain documents resulting from the records of the safety management systems of the parties involved (thematic group 4). This category is important for the resilience engineering research as the fact that documents are not updated can mean that they are not being used in the actual work of the system. However, there was no single recommendation to give up the development of certain documents or change their form in such a way as to reduce the difference between “work-as-imagined” and “work-as-done”. Due to this difference, hazard identification based on “work-as-imagined” may have potentially significant deficiencies, and the risk of certain hazards is not at all perceived at higher levels of organisation [1].

The largest and least homogeneous group is the group of direct orders concerning issues other than surveillance, trainings and documentation updates (thematic group 5). Most of the recommendations included in this group are direct responses to an event and seek to eliminate the sources of hazards or at least significantly reduce exposure. It should be borne in mind, however, that increasing the ability of a system to reduce the risk of certain hazards can result in reducing such ability for other types of hazards [21]. An example which raises certain doubts may be the recommendation to clarify the duties of the level crossing attendant by indicating, inter alia, the specific window of the station, through which signals are to be given. Such provision makes it impossible for the level crossing attendant to react to changing conditions, such as weather: dazzling sun, wind, or hail.

In about 65% of cases, the recommendations issued by the NIB only relate to a part of the railway system. When the range of application of a recommendation is limited, its full potential to strengthen the railway system’s resilience will not be used. This is, in a sense, justified in the case of recommendations requiring a considerable financial input, such as the redevelopment of transit station posts. This phenomenon is described in the literature, pointed out, among others, by Lundberg et al. [16], calling it “what you fix depends on the cost-benefit balance”. Less understandable are limitations of recommendations of a primarily organisational nature, for example:

- more realistic (longer) times of vehicle handovers between train driver crews;
- synchronisation of clocks in power supply systems, speech recorders and speed recorders on railway vehicles;
- recording the image from external cameras to hard drives.

In the first case, the application of recommendations may help increase the awareness of the vehicle’s technical state. In the second and third case it may affect the ability to learn from incidents and normal work (features 3 and 4, according to [5]). All of the recommendations cited were directed at only one carrier, and the last one only concerned one vehicle manufacturer.

6. Conclusions

On the basis of the analysis of the recommendations issued by the Polish NIB as a result of the investigation of railway accidents in 2007–2016, it can be concluded that recommendations can positively influence the resilience of a railway system. To this end, the following comments were made on the preparation of recommendations in a way that takes into account the need to improve the resilience of the railway system.

1. It is advisable to formulate recommendations in such a way as to transfer responsibility for developing detailed solutions to an interested entity, but these recommendations should not exceed the actual competence of a given entity.
2. Recommendations to increase supervision and carry out additional controls and audits should also indicate the need to review the validity of existing procedures.
3. Recommendations to update documents should stipulate an analysis of the validity of the documents in their current form and the reasons why a non-compliance was not discovered before the event occurred.

In addition, it seems reasonable to develop a database of training materials which would include causes of adverse events. These should be made available in such a form that they can be used for the mandatory periodic training of personnel involved in the safety of the railway system.
References

C-IED Polygon – New trends in Military Training

J. Sobotka¹, M. Benda²

¹Faculty of Military Technology, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: jan.sobotka@unob.cz
²Faculty of Military Technology, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic, E-mail: martin.benda@unob.cz

Abstract

The paper deals with modern trends in the training of the Corps of the Czech Armed Forces. New modern training ground is being built in the area of the former airport in Bechyně. In the area of the former airport in Bechyně there is located the 15th Engineer Brigade, which is the main part of the Czech Corps of Engineers. Soldiers of the 15th Engineer Brigade are responsible for the design, construction and operation of this training ground. The main subject of training at the polygon is “Counter - Improvised Explosive Devices”.

KEY WORDS: training, counter - Improvised Explosive Devices, polygon

1. Introduction

Improvised Explosive Devices (IEDs) have by far the largest share of coalition losses in Afghanistan, but also in other countries around the world. It can therefore be said that the main enemy of coalition troops are IED charges, not the insurgents themselves or other terrorist and criminal groups. Czech Army has also responded to the use of IEDs in recent years. For several years, it has been building, modernizing and expanding an C-IED Polygon at the former airport in Bechyně, which is the seat of the 15th Engineer Brigade (15th EB). The C-IED Polygon is designed primarily for training in the fight against booby-trapped explosive systems.

The C-IED Polygon is used to train specialists of the Army of the Czech Republic prepared for reconnaissance, removal, disposal of ammunition and improvised explosives. Polygon is also intended for other units of the Ministry of Defense, part of the Integrated Rescue System (IRS), but also units of foreign armies. The whole facility also serves ordinary soldiers of the Czech Army, who will be given a unique opportunity to try the fight against the IEDs in an environment that faithfully simulates the conditions of Afghanistan. In Fig. 1 you can see special Training of the EOD team on the C-IED Polygon in Bechyně.

2. The Purpose of the C-IED Polygon

The C-IED Polygon faithfully copies Afghan roads, urban and landscape specifics typical of Afghanistan. The aim was to build roads and their surroundings according to Afghan customs (specific surface and width of the road, hard shoulder, dimensions of culverts, the height of curbs or the width and depth of ditches along the road). Czech soldiers will get a chance to realistically practice individual scenarios of IED combat (reconnaissance, road search, selection of suspicious places, IED attacks, etc.) in peaceful conditions. Instructors can clearly show "pupils" places ideal for IED placement (e.g. water culvert) or to draw attention to suspicious situations.

Part of the Czech C-IED initiative is also the creation of communication channels for the immediate
incorporation of the latest knowledge about the enemy's activities in the field of IEDs. The journey from obtaining information about the enemy's tactics, techniques and procedures to its incorporation into the training scenario at the C-IED Polygon usually takes no more than three months and can very often be delivered to practical training immediately after evaluation, i.e. within a few weeks. ACR units can thus practice their skills in solving practical scenarios based on real incidents in which improvised explosive devices were used with a minimum of time delay.

The Department of Technical and Information Support of the EOD of the 15th Engineer Brigade, on whose initiative the C-IED Polygon was established, has a great deal of credit for the functioning of this polygon. The Department of Technical and Information Support of the EOD (DTIS EOD) continuously collects information on enemy activities related to ammunition and improvised explosive devices and analyzes the enemy's activities. He can verify his own and allied countermeasures and transfer experience from current foreign operations to the training of units of the Army of the Czech Republic.

The first draft of the polygon was created on the basis of experience from similar workplaces abroad and its author was experts from DTIS EOD (Fig. 2). Polygon was located in the western part of the military area of the brigade and its area was about 200 hectares. The polygon was divided into four basic parts:

1. ZONA A – Afghan Landscape;
2. ZONA B – Wooded;
3. ZONA C – Urbanized;
4. ZONA D – Battlefield.

Zone A consisted mainly of roads with culverts, small bridges and FOB (Force Operation Base). Zone B was called forested and was destined for training soldiers in a forest environment. Zone C was used for training in urban and rural environments. There were specially adapted training buildings and water canals typical of the Afghan landscape. The last zone D was designed primarily for training combat drills.

The space of the polygon is continuously modified and modernized and its current appearance is evident from Figure 3. The trend of the training ground is to build mostly mobile objects, which can be moved in various ways within the polygon. Therefore, it is possible to adjust the layout of the polygon to correspond to current trends in soldier training.

The use of sharp ammunition in all weapons is prohibited in all areas of the polygon. On the other hand, zones A, B and D (Fig. 4) are intended for the handling and use of charges, plastic explosives, industrial explosives and homemade explosives up to the equivalent of a trinitrotoluene - TNT (the maximum weight of the charge is 200 g). They are also designed for firing individual charges up to a maximum weight of 200 g TNT equivalent or non-electric and one electric firing circuit, including a charge up to a total weight of 200 g, tools powered by cartridges (without bullets) and the use of electric initiators, detonation tubes, detonating cord and pyrotechnic imitations. The use of these resources allows for effective and highly professional training of soldiers.

### 3. Geodetic Survey and Project Documentation

Place, which was chosen for the construction of the C-IED Polygon, was used in past as a temporary concreting plant and later as a polygon for training military driving school. The group of experts from Department of Engineer Technology was sent in the construction site in Bechyně. This group assessed the construction site selection and
utilization of existing roads. It was found that some existing roads could be partially used.

Then the group of geodesist from Military Geodetical and Hydrometeorological Office in Dobruška was sent there. The task of this group was to draw up the geodetic surveying of the area of interest. The data from geodesists included the text file with surveying (this file includes spot marking, x and y ordinate and altitude), georeferenced satellite images (in the format *.TIF, *.TFW) and Microstation situation data in the format *.DGN. All these drawings and surveying were processed in Universal transverse Mercator projection system (UTM WGS 84, Czech Army as well as NATO use this projection system). Finally geodesists saved all data on the Information Portal of Engineer Corps. It is a server for collecting and sharing engineer data. There was established a new folder, which was used for saving and sharing of the important data about the C-IED Polygon.

The whole project documentation was created by software AutoCAD Civil 3D. AutoCAD Civil 3D is a design and drafting program that supports a wide range of civil engineering tasks. AutoCAD Civil 3D is object application built on the platform of the program AutoCAD Classic. AutoCAD Civil 3D includes dynamic flexible connection of 3D objects and design data, maintains intelligent object relationships - through a single “super-model” is a change in the design of dynamically updated throughout the project, which is considerably more efficient and accurate work. This Software was used for planning of tertiary roads, defense walls, FOB and mobile devices which create the main part of the polygon.

The design of tertiary roads was the next step. First, it was necessary to create the digital elevation model as a digital representation of ground terrain from an area of interest. Points from a text file were imported in the program AutoCAD Civil 3D. The digital elevation model of the terrain TIN type was created from points mentioned above (TIN surface is composed of the triangles that form a triangulated irregular network). Digital elevation model was the fundamental element for projection of tertiary roads and defense walls. Directional solution of the new roads followed the existing roads, if it was possible. Designed parameters of the tertiary roads: road width 4.2 m, slope-sided 3% in direct and 6% in the curve, tilting of the road was done around the axis, design speed 30 kilometers per hour, minimum radius of the circular arch 12 m and maximum 300 m. There were designed seven tertiary roads with total length of the roads approximately 1200 m. Height surface solution of the tertiary roads followed the existing terrain, if it was possible. In the tops of the intersection angles were designed leveling curves with radius 200 m. You can see the digital terrain model processed in the program AutoCAD Civil 3D in Fig. 3.

![Fig. 3 The digital terrain model](image)

There were also created the corridors of the tertiary roads. The roads were designed as a gravel road with the volume of traffic class IV. Drainage of the tertiary roads was solved by the triangular ditch with min. depth 0.2 m below the outfall of the plain. New Roads will be linked to the existing concrete tertiary roads. Finally, defense walls were designed. Excess soil from the construction of tertiary roads will be used for the construction of the Defence walls. There were designed four defense walls (in total), the total length of these walls is approximately 195 m, high of the walls is about 3.5 m above the road axis, and gradient of the wall slope was 1:2.5 (this slope guarantees slope stability). All slopes of the Defence walls will be provided with erosion control measures slopes will be sown special grass mixture.

All drawings were published in format *.DWF. This format allows quick, safe and effective electronic publishing drawings in the internet and intranet environment. DWF files are highly compressed data and they are smaller and faster to transmit than the original CAD drawings and models with external links. DWF files are Electronic drawings containing all styles of drawing, drawing scale and leaves [1]. Drawings could be consulted before printing with the client and the building authority.
The revised drawings were placed on the Information Portal of Engineer Corps. There was established a new folder, which was determined for saving and sharing of the important data about the C-IED Polygon. Then the whole project documentation was hand over to the military building authority. After obtaining a building permit, the construction of the polygon began. The construction took place by the own forces of units from Bechyně. The first phase of the construction of the polygon was completed in 2014.

Since then, many changes have taken place at the polygon, probably the largest ones in the course of 2019. The new appearance of the polygon is evident from Fig. 4. The C-IED Polygon was enlarged by more than 60 hectares. The polygon was newly divided into six zones. In the future, it is planned to reconstruct the FOB and create a blasting pit, where it will be possible to perform blasting work up to a weight of 1 kg of TNT equivalent.

![Fig. 4 The C-IED Polygon 2020](image)

4. Conclusions

As follows from the Security Strategy of the Czech Republic (2011) [3], the current security situation in the Czech Republic is at a good level. Positive relations with neighboring states and membership in the EU and NATO create a disposition for a stable security environment and the risk of direct military assault is low. The prerequisite is rather asymmetric threats that could affect the level of the security environment. Although the situation in Europe appears to be stable, conflicts beyond its borders may also have a response to our security. Foreign missions are thus one of the main tasks that the army performs today to ensure collective security.

During their duties, soldiers abroad face many threats. They are at risk of attack by the enemy and often move in areas marked by previous war conflicts with the occurrence of a significant number of landmines and ammunition elements. Although the majority of missions are peacekeeping or humanitarian, and the units are not intended to directly suppress the enemy, their risk is evidenced by the number of soldiers who were honored with a badge for combat contact.

The importance and number of IED assistance attacks are likely to increase in the future. From the enemy's point of view, this is an effective and efficient way to fight a much more technically advanced and trained opponent. It is a cowardly tactic, but honor is not played in the war. Therefore, it is very important to prepare soldiers well and effectively for this type of combat. I am convinced that the C-IED Polygon is a very good space for training not only Czech soldiers. In the future, it would be good to continue working on its maintenance and modernization.

References

**Study of Vehicle ESP System and Analysis of Vehicle Dynamics**

V. Chandrasekaran¹, V. Lukoševičius²

¹Kaunas University of Technology, Studentu st. 56, LT-51424 Kaunas, Lithuania, E-mail: vinoth.chandrasekaran@ktu.edu
²Kaunas University of Technology, Studentu st. 56, LT-51424 Kaunas, Lithuania, E-mail: vaidas.lukosevicius@ktu.lt

Abstract

Study about the Electronic stability programme (ESP) system and analysis the various properties like influence skidding, understeer, oversteer, and rollover specific car model Lamborghini Aventador LP 700 – 4 was chosen and tested by using various regulations in modelling simulation software veDYNA. The testing regulations such as steer step, double lane change, slalom test, circle drive and mu-split was used with varied parameters to know about the limits of the vehicle in various conditions. The graphs generated in the plot - veDYNA software was used to analyse the yaw rate, yaw angle, roll angle, sideslip angle, steering wheel angle and lateral acceleration of the vehicle.

The aim of the research is to study about the effectiveness of ESP system using theoretical methods and apply various methods leading to skidding, understeer, oversteer, and rollover using vehicle simulation software veDYNA which is linked with Matlab/Simulink interface.

**KEY WORDS:** ESP, Matlab, understeer, oversteer, skidding, rollover, yaw stability, roll stability, braking, vehicle dynamics

1. Introduction

Electronic stability programme (ESP) is an active safety system which has been evolved from antilock braking system (ABS) and traction control system (TCS). Electronic stability programme is also called as electronic stability control (ESC), vehicle stability control (VSC) or dynamic stability control (DSC). It was mainly introduced into automobile industry by R. Bosch to control the vehicle from three important conditions such as skidding, self-steering behaviour (oversteer and understeer), and rollover [1].

The main function of ESC is to increase the performance of the vehicle by allowing the driver to drive the car in the intended path during an emergency situation or extreme manoeuvres to avoid rollover (e.g. fast cornering or lane changing with emergency braking). It also increases the vehicle stability by decreasing the loss of traction (skidding). With the continuous rise in demand for the vehicle by the people for traveling and transportation of goods, which has led to the rise in a number of the vehicle produced every year by the automotive industry. Further research and advancement in the field of automotive engineering have to lead to advancement in the active and passive safety vehicle system. More system like ESP should be invented to increase the stability of the vehicle and to decrease the number of fatality rate.

The research study [2] was done using veDYNA vehicle simulation software to compare vehicle system with and without ESP which shows the differences such as sideslip angle, steering wheel angle and vehicle trajectory of the vehicle. The author had also compared the values of the redesigned cycle with Duisburg cycle to show the effectiveness of the ESP system.

In the research [3] was written that ESP is an active safety system which has been very effective and had reduced the number of fatalities in accidents and avoiding rollovers. It has also been concluded that ESP increases the stability of vehicles by controlling the yaw rate and lateral acceleration.

The study [4] describes the working principle of electronic stability System in the theoretical method as well as by using the simulation software when the ESP system is disabled and enabled. It has been concluded that the ESP braking system can increase the vehicle stability and vehicle simulation software like veDYNA, MSC.Adams and Carsim decreases the cost of testing.

The paper [5] describes the importance of vehicle simulation software in the testing of ESP system using various testing methods to obtain accurate results rather using experimental methods in outdoor conditions which requires lot of time and money. It was also found out that the roll stability control and yaw stability control stabilized the self-steering behaviour and rollover rate in the presence of ESP system by comparing the graphs generated from the vehicle simulation software.

The research [6] describes the testing of yaw stability control mode in extreme conditions like snow in slalom method by using vehicle simulation software is better when compared to outdoor testing conditions. It is difficult to test vehicles Yaw stability control in Scandinavian countries where the temperature is very low with extreme weather conditions like snow, ice which makes really difficult for the automotive car makers to test the vehicle.

The study was done by Insurance Institute for Highway Safety on “Electronic stability programme - reducing multiple-vehicle crashes as well as single-vehicle” [7] clearly shows that single vehicle accidents are more when compared to multiple vehicle crashes. It is being confirmed by this study that ESP can reduce single vehicle as well as
multiple-vehicle crashes. The highway institute also studied the effectiveness and importance of ESP system in saving lives of road users. Researchers made a comparison of vehicle crashes for passenger cars, SUV with ESP system optional and mandatory from 2001 - 2004 and found out that fatality rate of single vehicle accidents reduced a lot when the car is equipped with ESP system (Fig. 1).

Fig. 1 Using vehicle ESP “on” and “off” [1]

According to the Federal Motor Vehicle Safety Standards “Electronic stability control systems; controls and displays of national highway traffic safety administration” [8] - Department of transportation it is mandatory for all the passenger cars, multipurpose passenger vehicles, trucks, and buses to be equipped with Electronic stability programme. NHTSA states that installation of ESP system reduced the single-vehicle accidents by 34% and single vehicle accidents of sports utility vehicle by 59%. ESP has the capacity to avoid rollovers by 71% of passenger’s cars and 84% of the SUV rollovers. From this NHTSA study, it is clearly evident that ESP plays a huge role in preventing rollovers and accidents.

The study [9] shows the different types of studies involving the reduction in rate of single-vehicle crashes when the vehicle is equipped with ESP system. The study also states about the involvement of ESP system in low friction surfaces when the road surface is covered by snow or ice. From this study, it is very clear that the ESP should be mandatory in all vehicles.

In the research [10] the ESP systems were tested in different vehicles by male and female drivers and it was found that vehicle equipped with ESP system was able to control the vehicle at high speed. The overall investigation leads to the conclusion that 34 percent of drivers gained more control of the vehicle if the vehicle is equipped with ESP. The comparison was done between SUV and passenger car in different conditions without ESP system, which further lead to rollover in SUV due to the high centre of gravity and skidding in passenger cars due to light weight and loss of traction in tyres.

The regulations stated by automotive industry standards on “Electronic stability control systems” has many rules and test procedures to be followed for the vehicles fitted with ESP system in India. In order to find the lateral acceleration, side slip angle, yaw rate, understeer and oversteer of the vehicle certain requirements such as general requirements, performance requirements, test conditions and test procedures are performed. By this regulation, it is concluded that ESP system can pass the test only if it meets the regulations given by the AIS 133.

The literature review shows that the electronic stability programme should be made mandatory in all vehicle as it improves the stability of the vehicle and avoids accidents in extreme conditions like skidding, understeer, oversteer, and rollover. It is also clear that availability of more vehicle simulation software in the automotive industry like veDYNA can reduce the time, money and human error in the vehicle testing.

The work is done to investigate the behaviour of vehicle during skidding, self-steering behaviour (understeer, oversteer) and rollover by using the theoretical principle of ESP in simulation software veDYNA/Matlab. For the better understanding of the vehicle behaviour, particular car model (Lamborghini Aventador LP 700 - 4) has been chosen and all the parameters for this car are fed to the veDYNA vehicle simulation software. According to the ECE, AIS regulations test such as double lane change, slalom test, steady-state circle drive, steer step and mu-split was experimented and comparison from the simulated graph are made to study about the ESP system.

2. Theoretical Framework

The main function of ESP is to increase the performance of the vehicle by allowing the driver to drive the car in the intended path during an emergency situation or extreme manoeuvres to avoid rollovers (e.g. fast cornering or lane changing with emergency braking). It also increases the vehicle stability by decreasing the loss of traction (skidding). Electronic stability programme is also called as electronic stability control or dynamic stability control. The Electronic stability control was first introduced by Robert Bosch and it was used in production by Mercedes-Benz (S) Class sedan in 1995. When the journalist applied sudden brakes in order to avoid hitting the moose on the highway, which lead to rollover of Mercedes-Benz A class in October 1997.

2.1. Cause of Rollover

A rollover happens more frequently while cornering and during the extreme manoeuvre. They can happen due to
several factors such as vehicle type, road conditions, environmental factors and behaviour of the driver. The causes of rollover can be classified into different types

**Vehicle type.** Rollover mainly depends on the type of vehicle being driven by the driver, as the centre of gravity of the vehicle plays a major role in causing the vehicle to rollover.

**Speed.** Most of the rollover happens at high speed which causes the driver to make counter steering to the desired direction. Rollovers due to speed are reported more on highways and roads where the speed limit is very high.

**Alcohol.** An investigation done by highway department said that alcohol can make the driver lose control of the vehicle and lead to rollover. Influence of alcohol had led to more number of rollover accidents.

**Location.** Rural roads account for high rollover incidents than any other type of roads. As the roads in the rural area are without a proper guardrail, median and road sign boards.

**Routine driving.** Daily commuting by people over long distance may lead to speeding, distraction, impaired driving which may further lead to a rollover accident.

**Single-vehicle crashes.** This type of vehicle crash accounts for more than 85% of a rollover not involving any other types of vehicle crashes, so it means that driver behaviour is the main reason for rollover incidents.

**Types of rollover.** Rollover occurs in two different ways and can be classified as tripped and untipped. Untipped rollover occurs very less when compared to tripped rollover and they mostly occur in heavy vehicles like bus, truck. It happens during an extreme manoeuvre at high speeds to avoid a collision which leads to untipped rollover. Tripped rollover accounts for 95% and there are many reasons for this type of rollover where the vehicles get tripped due to the guardrail, objects on the road which makes the vehicle to skid or turn around causing tripped rollover. When the vehicle travels at high speed it loses control as the driver intends to take a right turn, where the left side of the car touches the guardrail at high force causing the vehicle to rollover. A rollover happens due to the steep slope and it happens mostly in off-road vehicles when the driver evaluates the slope and tries to turn left or right causing the vehicle to rollover from top of the slope. It also happens when the driver climbs the slope and loses traction in the tyre which further causes the vehicle to topples over.

**Soft Soil.** This type of rollover occurs when the driver intends to take a sharp turn on the road curves and the vehicle takes a sharp turn where one side of the wheel touches the soil, pavement, snow etc. losing the adhesion coefficient decreases making the vehicle to slip sideways and rolling of the wheels occurs which causes a rollover.

### 2.2. Cause of Skidding

Skidding mostly occurs when the vehicle travels at high speeds on snow, stone or uneven road surface when a tyre loses the contact with road surface. They can also occur due to very hard braking or accelerate very fast suddenly in the corner, forcing the vehicle to skid or allowing the driver to lose control of the vehicle. It happens in the vehicle due to loss of traction in the front or rear of the tyre and they can further lead to rollover if a system like ESP is not present in the vehicle.

### 2.3. Cause of Oversteer and Understeer

Self-steering behaviour is one of the characteristics of vehicle dynamics and it can decrease the stability of the system. Oversteer happens when the vehicle turns more than the intended path made by the driver and understeer happens when the vehicle turns less than intended path made by the driver.

### 3. Modelling in veDYNA

The modelling and simulation in vehicle simulation software veDYNA involve a lot of procedure to get the desired output characteristics of the vehicle. For the better understanding and research purpose, the specific model of car was chosen and tested under various conditions to understand the situations leading to oversteer, understeer, and skidding. Modelling in veDYNA consist of three parts such as vehicle configuration, simulation control, and user procedure [fig. 2]. The specific model Lamborghini Aventador LP 700 – 4 was chosen for testing under different conditions and parameters such as general vehicle data, front axle, rear axle and drive train were fed into the veDYNA software. These parameters were further used for further simulation procedure. There are four different types of sections in vehicle configuration of veDYNA. The general vehicle data consist of vehicle dimensions, mass, and load, aerodynamics and brake system. In this step vehicle dimensions such as vehicle height, wheel track front, vehicle width, wheel track rear, wheelbase, vehicle length of the vehicle was calculated and fed into the vehicle dimension section and then in the mass and load section, the mass of the vehicle is given which further displays the vehicle centre of gravity (COG). In the brake system of the vehicle, brake pressure was evenly distributed as 50% in the front and 50% in the rear and for the aerodynamic properties, the assumption was made by the software on its own without the side wind force acting on the vehicle.

The front axle system in the veDYNA consists of several components such as a tyre, brake, steering, axle mass and inertia, initial wheel orientation, axle kinematics, axle compliance, spring, damper and anti-roll bar. The front tyre is chosen according to European norm ECE R30, front brake friction coefficient as 0.35, steering as parallel steering and for axle mass and inertia, initial wheel orientation, axle kinematics, axle compliance, spring, damper, stabilizer values were assumed and given automatically by the veDYNA software. The rear axle system in the veDYNA consists of several components such as tyre, brake, axle mass and inertia, initial wheel orientation, axle mass and inertia, initial wheel
orientation, axle, kinematics, axle compliance, spring, damper, stabilizer. The front tyre is chosen according to European norm ECE R 30, rear brake friction coefficient as 0.35, and for axle mass and inertia, initial wheel orientation, axle kinematics, axle compliance, spring, damper and stabilizer values were assumed and given automatically by the veDYNA software. The drivetrain consists of an important system like the engine, driveline, manual transmission or automatic transmission.

![Fig. 2 Specification of vehicle characteristics](image)

### 4. Simulation Results

**Steer step test.** The roll angle becomes high when there is an increase in yaw rate of the vehicle. When the lateral force in the front tyre was changed from 3180 N to 5000 N, the tyre loads at the inner left wheel became zero due to the high lateral force acting on the tyre and the wheel lifts. So, increasing the lateral force increases the lift of the wheel, which further leads to rollover at later on stage. The roll angle is abruptly increased when the lateral acceleration force is more on the tyres. The roll angle becomes high when there is an increase in yaw rate of the vehicle. When the lateral force in the front tyre was changed from 3180 N to 5000 N, the tyre loads at the inner left wheel became zero due to the high lateral force acting on the tyre and the wheel lifts. So, increasing the lateral force increases the lift of the wheel, which further leads to rollover at later on stage. The roll angle is abruptly increased when the lateral acceleration force is more on the tyres [Fig. 3].

![Fig. 3 Steer step yaw rate response due to steering wheel input graph](image)

**Go steady-state circle drive.** In the circular drive, method manoeuvre was changed to circle drive, driver as basic, road type as two lanes with a circle and flat, trace as circle drive and user procedure as a steady-state circular drive. For this type of testing two tests were done, where the force in the axles was changed in the front and rear axle. During the first test, lateral force in the front axle was increased and in the second test lateral force in the rear was increased to test the self-steering behaviour. The generated graphs show the understeer and oversteer behaviour when the force is changed on the front axle and rear axle [Fig. 4].

**Go-braking-on-mu-split.** In this method manoeuvre was changed to mu-split, driver as basic, road as straight and flat, trace as a brake on mu-split and user procedure as go braking on mu-split. For this method test was done for two different coefficients of friction. The generated graphs [Fig. 5] show the braking effect on the left and right side of the road with a different coefficient of friction. From the generated graph 1, it can be seen that the yaw angle of the vehicle is more when the friction coefficient is higher on one side than on the other side. It can be seen from the graph 2, that the yaw rate is very high when the skidding occurs, as the coefficient of friction is very less on the left side which leads to high yaw rate.
Fig. 4 Steady-state circle drive yaw velocity amplification oversteer graph

Go slalom: slalom test. In this method manoeuvre was changed to slalom, driver as basic, road type two-lane as straight and flat, trace as slalom and user procedure as go slalom.

Fig. 5 Mu-split yaw angle graph

Fig. 6 Slalom roll angle graph

Fig. 7 Double lane change lateral acceleration graph
From the generated graphs [Fig. 6] of three different vehicles at 80 km/h, it can be seen that yaw angle of the truck is very high when compared to car and SUV. The high roll angle is due to high centre of gravity, track width and mass of the vehicle.

**Double lane change test.** In this method, manoeuvre definition was changed to circle drive for longitudinal, lateral and constraints. The two tests were done at different speed at 80 km/h and 160 km/h, using the same vehicle configuration. By double lane change method, the rollover rate was tested. The generated graphs [Fig. 7] show the test results for two different speeds in a double lane change at 80 km/h and 160 km/h. From the graphs, it is evident that the lateral acceleration of the vehicle at 160 km/h is very high when compared to lateral acceleration at 80 km/h. High lateral acceleration force will lead to rollover accidents.

5. Conclusions

The ESP working principle was studied to analyse the conditions leading to skidding, understeer, oversteer, and rollover in the vehicle:

1. For the steady state drive, when the force was changed in the front axle oversteer clearly happens at 40 km/h and understeer happens at 26 km/h. It is well noted that high axle force leads to understeer and oversteer of the vehicle.
2. In the steerstep test when the force of 3180 N and 5000 N was applied in the front axle, the yaw rate in the front axle was found by 0.34 for 3180 N and 0.36 for 5000 N.
3. Braking on the mu-split at 80 km/h for two different coefficients 0.1 and 1, it was found that yaw rate went as low as -0.74 for 0.1 coefficient and it was constant for the coefficient of 1.
4. In the slalom test for three different vehicles at 80 km/h, the roll angle for car and SUV was 2 degrees and 3 degrees, whereas for the truck it was maximum of 6 degrees which clearly shows that heavy vehicles have high rollover rate when compared to light passenger vehicles.
5. For the double lane change, the steering wheel angle at 80 km/h was maximum of 100 degrees and at 160 km/h it was found to be 700 degrees. It shows steering angle is more at higher speeds of the vehicle.

References

Experimental Research of Solid Propellant Rocket Motor Internal Ballistics Characteristics

A. Fedaravičius¹, E. Slizys², A. Survila³

¹Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: algimantas.fedaravicius@ktu.lt
²Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: egidijus.slizys@ktu.lt
³Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: arvydas.survila@ktu.lt

Abstract

In this article the construction of the developed experimental research stand for solid propellant rocket motors, the block diagram of the research of internal ballistics characteristics, sensors, process measurement and registration equipment are presented. Using the developed experimental research stand of solid propellant rocket motors, the dependences of the thrust force, thrust coefficient and pressure change in the combustion chamber of the developed solid propellant rocket motor RM-12K on time were determined and the table of motor weight-dimensional and internal ballistics technical parameters was created. The obtained technical data of a rocket motor can be used in the development, research and practical implementation of rocket technology for various purposes.

KEY WORDS: rocket motor, thrust, specific impulse, pressure, thrust coefficient, measuring system, test stand.

1. Introduction

For a complete and ready-to-use motor, thrust, pressure and other characteristics, and for reliability tests, a specific test stand is required. With the help of a test stand, the existing motor can be tested under static conditions, the motor-generated thrust, motor-generated pressure, and temperature in the combustion chamber, the burning rate of the propellant can be determined and the various inaccuracies that were not anticipated during the motor design and production phases can be evaluated. Also, a test stand can be used to check the case deformation both when the motor is performing and when the propellant is depleted, as the motor can expand due to temperature, thereby damaging the structural elements of the rocket.

Many research groups which are dedicated to thrust systems design using relatively similar methods for propulsion system thrust measurements [1, 2]. The most common thrust measuring systems are hydraulic [3], piezoelectric [4] or load cell based [2]. Hydraulic systems are losing interest in thrust measurements because of more reliable electronic measurement systems. The most robust and versatile are the load cell based measuring systems because of their capability to use the same load cell for different ranges of thrust measurements. In this paper we describe a load cell with two working points for testing different thrust rocket motors.

Depending on the orientation of the rocket motor, there are 3 main types of rocket test stands. These are horizontal stands, vertical stands with the nozzle facing upwards and vertical stands with the nozzle facing downwards. Each of these orientations have their advantages and disadvantages. Nowadays the most used orientations are the horizontal for medium and large sized motors and the vertical orientation with the nozzle facing downwards for big facilities, although as previously stated in the state-of-the-art, a vertical orientation with the nozzle facing upwards might prove useful for compact solutions [5, 6]. A horizontal type of stand was used for RM-12K motor static testing. The horizontal orientation eliminates the necessity of taking into account the weight of the motor and thus eliminates the component of the propellant weight reduction into the measurements of the thrust. It also makes it easier for calibration purposes. The horizontal orientation reduces the overall weight and complexity of the structure and reduces the cost of materials.

2. The Static Test Stand for the Solid Rocket Motor Internal Ballistics

The horizontal stand for RM-12K motor static testing was projected using the SolidWorks® software. The stand was constructed using C45 calibrated steel profiles by cutting and welding them. The extra parts were machined using a CNC machine. The stand is fixed to the ground with 4 screws.

Horizontal test stand for solid propellant rocket motors up to 150kN thrust is shown in Fig. 1. The test stand can be easily adapted to motors of various lengths and diameters. Their length can reach 1.5 m and diameter up to 300 mm.

The illustration below shows a rocket motor mounted on a test stand during an experimental test when the motor producing maximum thrust (Fig. 2).

The rocket motor test stand is equipped with thrust, pressure, temperature sensors, instrumental amplifiers, data recording and acquisition equipment and HD resolution 200 Hz video digital recorders. Fig. 3 shows the configuration of the measurement equipment used to perform static firing of the rocket motor tests.
Solid propellant rocket motor tests were performed using this stand. Thrust and pressure characteristics were measured. The test results are given below (thrust-time – Fig. 4, pressure-time – Fig. 5).

3. Determination of Internal Balistics Characteristics from Test Data

Measuring the actual thrust and chamber pressure over the duration of the burn can yield valuable information, not only about the motor's performance, but also the performance of the propellant. Presented are the means to derive Total Impulse, Specific Impulse, Average Thrust, Characteristic Velocity and Thrust Coefficient from the test data. These are some of the key parameters relating to the performance of a solid rocket motor and propellant.

Total Impulse:

\[ I_{\text{total}} = \sum_{i=1}^{n} F_i \Delta t \]  

(1)

\[ I_{\text{total}} \] - total impulse; \[ F_i \] - motor thrust; \[ \Delta t \] - time increment.

Average Thrust:
Specific Impulse:

\[ I_p = \frac{I_{\text{total}}}{m_{\text{propellant}} g} \]  

\( I_p \) - specific impulse; \( m_{\text{propellant}} \) - mass of the propellant; \( g \) - gravitational constant.

There are two additional performance parameters that can be derived from the measurement of chamber pressure - Characteristic Velocity, usually referred to as \( c^* \), and thrust coefficient \( (C_f) \). Characteristic velocity is a figure of thermochemical merit for a particular propellant and is indicative of combustion efficiency.

Characteristic Velocity:

\[ c^* = \frac{A_{\text{throat}} \Delta t}{m_{\text{propellant}} \sum P_i} \]  

\( c^* \) - characteristic velocity; \( A_{\text{throat}} \) - nozzle throat cross-sectional area; \( P_i \) - motor chamber pressure.

The thrust coefficient, which is a factor that relates chamber pressure and thrust, may be calculated using the measured values of these two parameters. The thrust coefficient reveals to the experimenter how well the nozzle "amplifies" the thrust that would be obtained if the nozzle were a simple hole. Calculation of the thrust coefficient, \( C_f \), requires knowledge of thrust, chamber pressure and the nozzle throat cross-sectional area.

Thrust coefficient:

\[ C_f = \frac{F}{A_{\text{throat}} P_1} \]  

\( C_f \) is only valid during the steady-state duration of the burn. A graph of the results shows (Fig. 6) that the steady-state portion of the burn occurs between 0.4 seconds and 3.1 seconds. The average value of the thrust coefficient over the steady-state duration is \( C_f = 1.45 \). The calculation was performed with Matlab® software.

<table>
<thead>
<tr>
<th>Initial data</th>
<th>Obtained data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor length, m</td>
<td>1.15</td>
</tr>
<tr>
<td>Motor diameter, m</td>
<td>0.16</td>
</tr>
<tr>
<td>Propellant mass, kg</td>
<td>18.0</td>
</tr>
<tr>
<td>Full motor mass, kg</td>
<td>35.0</td>
</tr>
<tr>
<td>Nozzle throat diameter, m</td>
<td>0.044</td>
</tr>
<tr>
<td>Propellant type</td>
<td>ammonium nitrate-based (ANCP)</td>
</tr>
</tbody>
</table>

The obtained technical data of a rocket motor can be used in the development, research and practical implementation of rocket technology for various purposes [7, 8].
4. Conclusions

The obtained results show that the rocket motor testing stand can be effectively used to perform the static test of solid propellant rocket motors. After experimental testing the measured rocket motor thrust characteristics were obtained. Maximum thrust which was produced by the rocket motor was 13054 N, total impulse was 32115 Ns and specific impulse was 184 seconds. Other internal ballistic parameters, such as total impulse, specific impulse, average thrust, characteristic velocity, thrust coefficient and ect., can be easily calculated from the obtained measurement data.

ACKNOWLEDGEMENT

This work was supported by the Research Council of Lithuania, grant No. S-MIP-17-94 „Experimental Rocket: Research and Development

References

The Method of Transport Forecasting in the Efferta Enterprise

B. Kozicki¹, J. Tomaszewski², M. Stajniak³, S. Budek⁴

¹Military University of Technology, Kaliskiego 2, 00-908 Warsaw 46, Poland, E-mail: bartosz.kozicki@wat.edu.pl
²General Staff of the Polish Army, Rakowiecka 4a, 00-001 Warsaw, E-mail: jarek7@wp.pl
³Institute of Logistics and Warehousing, Estkowskiego 6, 61-755 Poznań, Poland, E-mail: maciej.stajniak@ilim.poznan.pl
⁴Military University of Technology, Kaliskiego 2, 00-908 Warsaw 46, Poland, E-mail: sebanunited10@gmail.com

Abstract

The article deals with a research problem which focuses on the analysis and evaluation of data on the transport of dietary supplements at Efferta enterprise and their forecasting for the future. The research began with the analysis and evaluation of primary data. The obtained results became a premise for choosing two methods for forecasting. Selected methods were analyzed and evaluated in terms of the selection of the best one. The best method was applied in order to conduct the forecasting for the future of the original time series. The rest of the obtained forecast has been analyzed and evaluated.

KEY WORDS: transport, forecasting, enterprise

1. Introduction

The evaluation of the visual observation regarding information recorded and processed by Efferta enterprise allows to state that it does not analyze, evaluate or forecast data for the future. This became a premise for undertaking research concerning the analysis and evaluation of the value of transported supplements for the past.

The purpose of this work is to conduct an analysis and assess the value of goods transported in the past, and based on it, to forecast for the future.

The following research problem was outlined for the adopted purpose of the study: why is the analysis and evaluation of primary data on the value of transported dietary supplements in the research subject important in their forecasting?

Then, the main research question was formulated, which reads as follows: will the conducting of an analysis and evaluation of data on the value of transported supplements in a dynamic approach allow to forecast them for the future?

The subject of the research is Efferta. However, the object of the research is the values of transported supplements by the subject of the research in dynamic terms. The research area is the region of the Republic of Poland. The research period covers the years between 2012-2019.

2. Analysis of the Research Problem in the Light of the Literature on the Subject

Nowadays, it is impossible to imagine carrying out the purchase and sale of goods without the proper functioning of transport. Transport is one of the main branches of the national economy and it has a huge impact on its development.

In the dictionary of logistics terminology, transport is defined as "a set of activities related to the movement of persons and material goods using appropriate means" [6]. However, in etymological terms, the term transport comes from the Latin word transportare, which means to transport and transfer [9].

The literature analysis regarding the term transport allows us to state that it is interpreted differently. According to W. Rydzkowski, transport is an activity that involves the provision of paid services, the effect of which is the movement of persons and / or loads from the point of posting to the point of collection and the provision of ancillary services directly related to these services [6]. Whereas A. Koźłak believes that it is closely related to the use of appropriate means of transport and transport infrastructure, the existence of economic entities that provide services as well as obtain financial results related to the transport activities [7].

The basic elements of transport are transfer and additional services. Transportation is a key activity during transport. It is related to the movement of the vehicle and its stopping and applies only to the load that is within the means of transport. In order to place goods on vehicles, it is necessary to perform manipulations at transport points. Some services require additional activities, especially in foreign trade [13].

Transport in the national economy can be considered as a donor and recipient [8]. Transport recognized as a supplier enables the exchange of goods and services. It involves the transport of various raw materials, materials for production (in industry, construction), and finished products for personal consumption. It supports the sphere of exchange of goods, both domestic and foreign ones. It is a continuation of production in the sphere of the turnover as the last phase of the broadly understood production cycle. In addition to the support of material production departments, transport also supports non-production departments, provides services to the population, meets individual
communication needs and promotes the development of tourism [12]. Transport as a recipient carries out transport investments.

It should be emphasized that transport cannot exist without fuel and electricity and, thus, depends on the mining and chemical industries and electricity production. Therefore, it can be assumed that transport and other production departments depend on each other [12].

Transport in its administering role has three main functions [10, 11]:
1) consumer-oriented, which means the satisfaction of transport needs by the transport services provided;
2) Production-oriented, which means the satisfaction of production needs by providing transport services, i.e. by creating conditions for economic activity, its stimulation and impact on the functioning of the market and exchange of goods;
3) Integrative, which allows the integration of the state and society through transport services.

Interpreting the above functions, it can be stated that the malfunctioning of transport becomes a barrier to economic development.

Transport has a negative impact on the health and natural environment. It is divided into two systems: vertical and horizontal.

The vertical classification of transport is based mainly on the environment within which the cargo is transported and on the way of displacement. Taking into account the environment for obeying orders, transport is divided into: air transport, water transport and land transport.

The division, which takes into account the type of transport means and transport routes, divides transport into six basic modes of transport: air, sea, inland, car, rail and transmission.

Forecasting is a key element of the planning process in the company management because its correct implementation allows the company to grow by making the right decisions related to the implementation of new investments [5].

Critical analysis of the literature regarding the definitions of a forecast and forecasting allows to state that they are interpreted differently by the authors. P. Dittmann states that "forecast is a judgment regarding the future of the forecast phenomenon - precise and uncertain" [5]. On the other hand, Z. Czerwiński believes that "by forecast, it is a judgement about a specific event occurring within a specified time with accuracy to the moment or period of time belonging to the future" [2]. In turn, E. Nowak states that the forecast is a predicted judgement about the development of phenomena and processes in the future based on elementary sciences [E. Nowak (red), Economic Forecasting, p. 10]. What's more, a forecast is called the judgment in various aspects by M. Cieślak [1] and J. B. Gajda [3].

The evaluation of the analysis of the term forecast is a statement that it is the result of the forecasting.

The definition of forecasting according to M. Cieślak [1] and A. Zeliaś [14] is understood as a rational and scientific prediction of future events. Whereas J. Gręh [4] believes that "forecasting (i.e. prediction) is a practical operation (activity) aimed at formulating a scientifically sound assessment, i.e. an estimate of the probable future state based on information from the past and substantive knowledge about a given fragment of reality being the subject of forecasting". According to P. Dittmann, forecasting is a rational, scientific prediction of future events [5].

The evaluation of the analysis of the term forecasting is the statement that it is a prediction of future events based on the analysis and evaluation of data from the past and the application of other regularities observed during the research on the construction of the model for forecasting. Forecasting is conducted in enterprises in various areas.

3. Multicriterial Data Analysis

The multicriterial analysis of primary data obtained from the research subject regarding the value of transported goods on a monthly basis in the years between 2012-2019 began with the search for the existence of regularities governing the examined phenomenon. For this purpose, research tools were used to demonstrate whether outliers and extreme values exist within the data considered. An important aspect will be to examine the distribution of the analyzed data, as well as to determine whether the time series considered is stationary or non-stationary. Obtained results from the analyzes carried out in Chapters 1 and 2, and visual observation of the line graphs of primary data will allow the selection of methods for their future forecast.

The analysis of primary data began with a sketch of a line graph, which is presented in Fig. 1.

![Fig. 1 Chart of linear primary data on a monthly basis in the years between 2012-2019, along with a trend line](image)

The evaluation of information presented in Fig. 1 is the evidence of the existence of a rising linear trend. The observed regularity was a premise for sketching mechanically the trend line in Fig. 1 and describing its function:
The alpha of the studied trend is 21,481.2601 and it indicates a growing trend of primary data. An important observed regularity is that the outlined primary data typically alternates around a trend line. The next stage of the analysis is to examine the distribution. For this purpose, research tools were used in the form of a normality chart with the Shapiro-Wilk test (Fig. 2).

Fig. 2 Normality chart with the Shapiro-Wilk test of primary data on a monthly basis in 2012-2019

The evaluation of the information presented in Fig. 2 is that the distribution of primary data is not normal. The next stage of the research was to look for regularities found in primary data. For this purpose, a research tool in the form of multiple regression was used. A multiple regression model of fourteen predictors was built. Then, it was analyzed and evaluated. The evaluation was that three predictors are relevant, which are summarized in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Raw data</th>
<th>December</th>
<th>t</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b^*$</td>
<td>680525</td>
<td>680525</td>
<td>680525</td>
<td>680525</td>
</tr>
<tr>
<td>St. error. of $b^*$</td>
<td>77191,5</td>
<td>77191,5</td>
<td>137082,9</td>
<td>137082,9</td>
</tr>
<tr>
<td>$b$</td>
<td>8,81606</td>
<td>137310,8</td>
<td>15,89550</td>
<td>15,89550</td>
</tr>
<tr>
<td>St. error. of $b$</td>
<td>0,000000</td>
<td>0,051004</td>
<td>0,089000</td>
<td>0,089000</td>
</tr>
<tr>
<td>$t(92)$</td>
<td>0,000000</td>
<td>0,051004</td>
<td>0,000000</td>
<td>0,000000</td>
</tr>
</tbody>
</table>

The evaluation of the data presented in Table 1 is that the model was built well, because $R_2$ was 0.74. Significant predictors were variables in the form of $t$, January and December. They show the existence of a linear trend of an increasing nature and seasonality.

The first stage of analysis and evaluation of selected forecasting methods was the division of the original time series into two parts. The first part will be used to make forecasts based on it, and the second one to evaluate the forecast made.

4. Forecasting

Fig. 3 shows the division of the original time series into the teaching part - blue and testing one - red.

Fig. 3 Line graph of the teaching and testing time series

Visual observation of the data presented in Fig. 3 allows us to state that the teaching time series consists of 84 elements, and the testing one series of 12.

The next stage of the research will be to predict the learning time series for twelve future periods using the Holt-Winters and ARIMA methods (Fig. 4).

Visual observation of the information summarized in Fig. 4 indicates that the best tailored forecast for the testing time series is the forecast made by the Holt-Winters method.

For research purposes, it was decided to compare two forecasts using a research tool in the form of MAPE. The results are summarized in Table 2.
Fig. 4 Graph of linear data on: teaching time series (from 55 to 84 element), testing time series, Holt-Winter’s forecast and ARIMA model (1.0.0) (1.0.0)

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of forecasts using the MAPE indicator</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>MAPE</td>
</tr>
</tbody>
</table>

The evaluation of the analysis of two methods of forecasting the teaching time series presented in Table 2 is that the best one is the Holt-Winters method because MAPE is the lowest for it and amounts to 0.305.

The obtained evaluation has become a prerequisite for choosing the Holt-Winters method in order to forecast the original time series.

The results of the Holt-Winters exponential smoothing method of the original time series are summarized in Fig. 5.

Fig. 5 Line chart of the original time series forecast of the Holt-Winter’s method for twelve future periods

The evaluation of the forecast of primary data for the twelve future periods presented in Fig. 5 is the observation of the upward trend.

The detailed results of the forecast made by the Holt-Winters method are summarized in Table 3.

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast of the original time series for twelve future periods made by the Holt-Winter’s method (2020)</td>
</tr>
<tr>
<td>Years</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
</tr>
</tbody>
</table>

The evaluation of the data summarized in Table 3 is that the highest forecast was in July and amounted to 2 924 367, and the lowest one in February 2 404 618. The arithmetic average of the forecast for 2020 was 2 604 839.2, while the median was lower and amounted to 2 600 778. The distribution of the forecast was right-skewed, more flattened.
than normal.

The next stage of the study was to analyze and evaluate the residuals of the obtained forecast made using the Holt-Winters method.

The analysis of forecast residuals began with an examination of critical forecasting errors as a result of a critical analysis of the literature. The results are summarized in Table 4.

### 5. Conclusions

The article analyzes and evaluates retrospective data on the value of transported goods using advanced research tools. For this purpose, line charts, histograms, box-plot graphs, normality charts with Shapiro-Wilk tests were used. In addition, a zero-one multiple regression model was built to confirm the observed relationships in the primary data considered. What is more, the original time series was brought to a stationary form using differentiation and logarithm treatments. The evaluation of the analysis carried out is a clear detection of the trend and seasonality, as well as methods that can be used to forecast primary data for the future. Thus, the goal of the work was achieved.

The article answers the following research question:

- Will conducting an analysis and evaluation of data on the value of transported supplements in a dynamic approach allow their forecast for the future?

The analysis and evaluation of primary data in the form of the value of transported goods allowed the selection of two methods for their forecasting: Holt-Winters’s method and the ARIMA model. In the diploma thesis both methods were analyzed and evaluated. For this purpose, the original time series was divided into two parts: teaching and testing. Then, based on the teaching time series, forecasting was made for twelve future periods. Then, an analysis and evaluation of the forecasts were made. As a result of using the MAPE indicator, the best method turned out to be the Holt-Winters forecast which was used to forecast primary data for the future. The sum of the value of the forecast received for 2020 is 31 258 070. Thus, the answer to the research question posed is as follows: the analysis and evaluation of forecast residuals is that the forecast is positive.

### References

Research of Tugboats Pollution in Klaipėda Port

A. Andruiltytė

Klaipėda university, Herkau Manto 84, LT-92294, Klaipėda, Lithuania, E-mail: agne.andruiltyte9@gmail.com

Abstract

The purpose of this research is to find how much pollution coming from tugboats to Klaipėda Port, while they are transporting constructions of ships builded in JSC Western Baltija Shipbuilding by platforms or assist large vessels in navigating the port channel. Research based by results got from navigational simulator that is situated in Klaipėda University. There are estimations of emissions and also possibilities of solving this increased pollution in Klaipėda city.

KEY WORDS: Tugboats, ship, emission, seaport, pollution

1. Introduction

In the modern age of globalization and information technology, a rare company or individual does not associate their daily activities with transport or the services it provides. The transport sector guarantees the smooth operation of all branches of the economy. Without it, production and processing companies, construction, agriculture, trade, post, services would stop. Cargo can be transported both domestic and international routes - by road, rail, water or air. Raw materials and equipment are supplied to industrial companies, and the products made from them are promptly distributed to customers whose geography is extremely wide. It is necessary for shopping centers to replenish the range of goods on a daily basis, for pharmacies and medical institutions - the list of medicines, etc. All this is mostly done by road, but it should be mentioned that a large part of various goods to and from Lithuania are transported by ships [1-6].

Oversized cargo transportation has grown in recent years, influenced by an expanding and ever-modernizing industry. The energy, electricity, chemical and construction industries are growing rapidly, requiring construction of extraordinary, non-standard dimensions and not always permissible weights. These cargoes are usually transported by ship, which can carry extremely large and heavy cargoes. Oversized cargo is also transported by road and sometimes by air and rail, but such modes of transport severely limit the dimensions and weight of the cargo.

Klaipėda port plays the most significant role in transporting oversized and heavy cargo in Lithuania. It is the largest and most important transport center of the Republic of Lithuania, where sea, land and railway roads from the east and west connect. The port employs 14 large stevedoring, ship repair and construction companies, and provides all services related to cargo handling and maritime business.

One of the companies that develops its activities in Klaipėda port is JSC Western Baltija Shipbuilding. This company focuses on the production of ships and their constructions, which are later combined into ships in larger ports. Port tugs are needed to transport barges from the port water area to large sea tugs. Despite the fact that port tugs are less polluting than sea tugs, they are also polluting the port of Klaipėda by emission. It is important to mention that port tugs also help large ships navigate the canal.

2. Situation Analysis

Improved port infrastructure, increasing loading and loading speed also affect the tug services segment - towing services must be performed faster and on time. Increasingly large ships are arriving at the port, whose downtime in the port is expensive and there is not much time to fill out paper documents. Also, as large vessels passed through the canal, it became necessary to perform towing services for several vessels at the same time.

Currently in Klaipėda port the main tugs are 6, which navigate the canal. They provide ship assistance and all marine related services to customers calling at the Port of Klaipėda/Lithuania and the Baltic Sea region. Ship assistance, escort, salvage, coastal towage, ice-breaking, diving, single point mooring services are main activities.

3. Methodology of the Research of Emissions from Tugs Operated in Klaipėda Port

This section provides a methodology for calculating emissions using data provided by the program and port tug characteristics. The characteristics of one of the port tug are given in Table 1.

<table>
<thead>
<tr>
<th>Tug name</th>
<th>Length, m</th>
<th>Breadth, m</th>
<th>Draft, m</th>
<th>Main engine power, kW</th>
<th>Auxiliary engine power, kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAK-4</td>
<td>26.4</td>
<td>8.8</td>
<td>4.8</td>
<td>1298.0</td>
<td>92.0</td>
</tr>
</tbody>
</table>
Despite the fact that the tug emits less emissions into the environment than, for example, a container vessel, they still pollute the environment. The main emission types from ships are carbon monoxide (CO), carbon dioxide (CO₂), sulfur oxide (SOₓ), mono – nitrogen oxide (NOₓ), particulate matter (PM). They all have factors, who helps to calculate emissions, using fuel consumption. The factors are given in Table 2. Also using navigational simulator “SlimFlex4Navigator” received data of the fuel consumption of the tugboat.

<table>
<thead>
<tr>
<th>Emission type</th>
<th>Marine diesel oil</th>
<th>Liquefied natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOₓ</td>
<td>0.1% from fuel consumption</td>
<td>0</td>
</tr>
<tr>
<td>NOₓ</td>
<td>10 g/kWh</td>
<td>4 g/kWh</td>
</tr>
<tr>
<td>CO</td>
<td>5 g/kWh</td>
<td>3 g/kWh</td>
</tr>
<tr>
<td>CO₂</td>
<td>3.2 g/kWh</td>
<td>2.8 g/kWh</td>
</tr>
<tr>
<td>PM</td>
<td>0.5 g/kWh</td>
<td>0.1 g/kWh</td>
</tr>
</tbody>
</table>

With these coefficients it is possible to calculate emissions by type using the formulas below.

Carbon monoxide emission:

\[
CO = P \cdot \Delta CO \cdot t / 60 ,
\]

where \( P \) – propulsion engine power, kW; \( \Delta CO \) – coefficient from Table 2, g/kWh; \( t \) – time of sailing, min.

Carbon dioxide emission:

\[
CO₂ = Q \cdot \Delta CO₂ \cdot t / 60 ,
\]

where \( Q \) – fuel consumption, kg/min; \( \Delta CO₂ \) – coefficient from Table 2, g/kWh.

Sulfur oxides emission:

\[
SOₓ = Q \cdot \Delta SOₓ \cdot t / 60 ,
\]

where \( \Delta SOₓ \) – coefficient from Table 2, g/kWh.

Mono-nitrogen oxides:

\[
NOₓ = P \cdot \Delta NOₓ \cdot t / 60 ,
\]

where \( \Delta NOₓ \) – coefficient from Table 2, g/kWh.

Particulate matter emission:

\[
PM = P \cdot \Delta PM \cdot t / 60 ,
\]

where \( \Delta PM \) – coefficient from Table 2, g/kWh.

Having these formulas and simulator data, can be calculated pollution from tugboat.

4. Calculations of Emission

To make more accurate amount of emission, was used navigational simulator “SlimFlex4Navigator” received data of fuel consumption of tugboat passing trough the port canal to JSC “Western Baltija Shipbuilding”. Sailing of tugboat took 35 minutes, was consumed 111,8 kg of fuel and the average engine power was 474,2 kW. The route is shown in Fig. 1 and Fig. 2.

Those emissions also can be applied for sailing of barges by tugboats from Klaipėda port, in that way all the calculated values are doubled.

First of all are calculated emissions when tugboat is fueled by diesel oil, average of fuel consumption is 1,86kg/min:

\[
CO = 474.2 \cdot 0.005 \cdot \frac{35}{60} \cdot 2 = 2.76 \text{ kg};
\]

\[
CO₂ = 1.83 \cdot 0.0032 \cdot \frac{35}{60} \cdot 2 = 0.006 \text{ kg};
\]
Secondly calculated emissions when tugboat is fueled by liquefied natural gas. So it means that does not emit \( \text{SO}_x \) emission. Another calculations given below:

\[
\text{SO}_2 = 1,83 \cdot 0,001 \cdot \frac{35}{60} \cdot 2 = 0.002 \text{ kg};
\]

\[
\text{NO}_x = 474,2 \cdot 0,01 \cdot \frac{35}{60} \cdot 2 = 5,54 \text{ kg};
\]

\[
PM = 474,2 \cdot 0,0005 \cdot \frac{35}{60} \cdot 2 = 0.28 \text{ kg}.
\]

Fig. 1 Tugboat route to Klaipėda's port canal

Fig. 2 Tugboat route to JSC "Western Baltija Shipbuilding" territory

Secondly calculated emissions when tugboat is fueled by liquefied natural gas. So it means that does not emit \( \text{SO}_x \) emission. Another calculations given below:

\[
\text{CO} = 474,2 \cdot 0,003 \cdot \frac{35}{60} \cdot 2 = 1,64 \text{ kg};
\]

\[
\text{CO}_2 = 111,8 \cdot 0,00275 \cdot \frac{35}{60} \cdot 2 = 0,36 \text{ kg};
\]

\[
\text{NO}_x = 474,2 \cdot 0,004 \cdot \frac{35}{60} \cdot 2 = 2,22 \text{ kg};
\]
\[ PM = 474.2 \cdot 0.0001 \cdot \frac{35}{60} = 0.06 \text{ kg.} \]

The parking of a tug in the port is not assessed, because at that time it connects to the port electricity. Given that, on average, a barge arrives eight times a year to transport cargo, it is possible to calculate how much emissions are emitted per year by operating one tug. The calculated values are given in Table 3.

<table>
<thead>
<tr>
<th>Emission type</th>
<th>Diesel oil</th>
<th>Liquefied natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOx</td>
<td>0.016 kg</td>
<td>0</td>
</tr>
<tr>
<td>NOx</td>
<td>44.32 kg</td>
<td>17.76 kg</td>
</tr>
<tr>
<td>CO</td>
<td>22.08 kg</td>
<td>13.12 kg</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.048 kg</td>
<td>2.88 kg</td>
</tr>
<tr>
<td>PM</td>
<td>2.24 kg</td>
<td>0.48 kg</td>
</tr>
</tbody>
</table>

5. Conclusions

From the calculated values, it can be seen that the emissions per year are quite high, given that this is only the pollution of one tug.

- Maximum emission, when tug fueled by diesel oil is mono-nitrogen oxides, it emits about 44.32 kg per year. When tug is fueled by liquefied natural gas this emission is lower – about 17.76 kg per year.
- Minimum emission, then tug fueled by diesel oil is sulfur oxide – 0.016 kg per year, with liquefied natural gas the pollution is zero.
- When tug fueled by diesel oil carbon dioxide emission is 0.048 kg per year, but with liquefied natural gas the pollution is higher – 2.88 kg per year. Nevertheless, it can be argued, if tug be fueled by liquefied natural gas, the pollution of environmental would be lower.

References

Modeling Postal Operations in Crisis Situation

L. Madleňáková¹, S. Turská²

¹University of Žilina, Univerzitná 1, 010 26, Žilina, Slovakia, E-mail: lucia.madlenakova@fpedas.uniza.sk
²University of Žilina, Univerzitná 1, 010 26, Žilina, Slovakia, E-mail: stanislava.turska@fpedas.uniza.sk

Abstract

The postal network of the national postal operator is characterized by legal requirements to ensure basic servicing of the territory. The capacity of postal offices (access and contact points) must be dimensioned according to the size of the demand as well as to the quality requirements (by law), both under normal conditions and in crisis situations. The modeling of queuing system can adequately demonstrate different situations. It is one of the applications of management decision support not only at the operational level. For example, it allows optimizing operations of post offices, modeling the number of postal counters, cash desks at a certain frequency of arrival of customers, etc. The paper presents a modeling of the functionality of a queuing system in a selected post office in a city district. We modeled real postal traffic, as well as the changes leading to a crisis scenario for the postal functionality.

KEY WORDS: modeling, simulation, queuing theory, postal traffic, crisis management

1. Introduction

Crisis do not arise by chance and their occurrence cannot be eliminated. However, the society and companies within should be prepared to it and also find the solution in a certain way, therefore to eliminate its adverse effects by appropriate management. The crisis management process should be a routine activity not only of crisis managers but of all managers working in an environment where there are various threats and risks. Any entity should not at first deal with the question of whether it will be affected by the crisis, but should look for answers to four key issues:

- the extent to which the crisis will limit or interrupt its activities;
- how long it will be affected by the adverse effects of the crisis;
- will be the expected negative consequences, damages and losses;
- What measures can be used to minimize the negative consequences of the crisis in the conditions of the given entity?

Crisis management is a relatively well-known issue nowadays. This term was allegedly used for the first time by the American president J.F. Kennedy in 1962 during the so-called Cuban crisis. Today, crisis management has found its position in international politics, the military, the economy, banking, ecology, health and social policy. Current practice shows that we are not adequately prepared for crises. Sociological research [5, 9, 11] suggests that the cause is often a feeling of stable security, health, social but also the economic environment in Europe when the crisis is considered a situation quite distanced from our environment. We are still facing a crisis caused by a pandemic. The state restrictions on the territory of the Slovak Republic were relatively strict and, with immediate effect and effectiveness, affected the operation of many economic entities and limited the social and economic activities of the population [11, 12].

2. Current State Situation

The current crisis has significantly affected the activities of many strategic companies, with the task of ensuring the necessary serviceability of the territory. It includes the provision of universal postal service. Following EU requirements, the government sets the basic requirements for the provision of the postal service and can adjust them in the event of a crisis.

The current situation shows that the postal company in many areas also replaces the services of the state when especially the client centers for handling the agenda of the citizens vs. state do not work or they operate in a restricted mode. Their role is taken over by the postal service company [24, 25]. The distribution of consignments increased in volume, even though imports of consignments from Asia and subsequently from some Western European countries were suspended. However, thanks to the closed brick and mortar shops and restaurants, the logistics activity at the regional level multiplied [6]. The universal service provider also had to adjust the provision of services and opening hours. Especially concerning safety and hygiene requirements. The restrictions were mainly related to the number of customers in operation (1 customer / 25 m²), distances between customers in the queue, but also the limited opening hours for the public. Another important aspect was the transfer of the performance of some services (delivery of registered items, money, etc.) from couriers to postal operations. All these restrictions can significantly disrupt the smooth provision of postal services at the post office (waiting for lines forming, the extension of waiting time, and unavailability of services). Lack of workforce can also be a negative phenomenon limiting postal traffic in a crisis [8, 18].
Similarly, the situation is changing in the conditions of other postal administrations, while alternative postal operators have also significantly reduced their logistics activities, especially towards abroad.

The paper points out the modeling of the situation in the post office under standard conditions, but also in a situation that may be caused by a crisis. The theory of Queueing theory systems aims to find the dependence between the nature of the input of requirements, the productivity of lines and the efficiency of service. Based on this knowledge, we can improve the operation of the system. When optimizing the system, there are always two goals: the highest possible use of the line and the minimization of customer time loss [16].

A significant shift in this area has been reached by Danish engineer Anger K. Erlang. It has been shown that the Queueing Systems model can be described, for example, utilizing a statistical process with a Poisson distribution. In general, this model can be described by so-called Markov chains, and knowledge and quantities taken from statistics are used to calculate the parameters [4]. The primary issue of Queueing theory is to determine the main attributes of the model, while the others are considered negligible for simplification. The task is to specify the input flow of requests, the method and mechanism of handling requests, including the number and arrangement of serving devices, the nature and behavior in the order, the order in which requests enter service, the way of output and the nature of service duration [2, 3].

Queueing theory can be classified from different perspectives. D.G. Kendall marking is used as a standard one. The most commonly used criteria are the nature and type of distribution of input request streams, the nature and type of distribution of service times, the discipline of waiting and the number of places in a queue, the queue/row mode and the mode and structure of the service [1, 10, 19].

Models of Queueing Systems can be solved in two ways, analytically or by simulation. Analytical methods - the result is a functional dependence of input and output requirements. If the assumptions of the mathematical model are significantly modified, it is necessary to proceed to simulation methods. We replace the system with a simulation model with the same probable characteristics and simulate the behavior many times on the model. In a system like the postal queue system, many random variables cannot be captured in analytically solving optimization problems. Therefore, it is appropriate to use a simulation method to bring the system model as close as possible to the real system [7, 12, 13, 15].

3. The Aim and Methods Used

The paper aims to model the system of collective service, which represents the selected post office in different conditions. The fundamental phase of modeling the Queueing theory is the static analysis of individual elements, i.e., the acquisition and processing of suitable data. Based on the assessment of empirical data, we proceeded to the description of Queueing theory using a mathematical model and the determination of essential characteristics. The elements have a stochastic character corresponding to an exponential probability distribution. The system operates four parallel service lines with one infinite queue and the service method is defined by FIFO. Statistical methods of qualitative feature analysis were used for modeling, such as the chi-square goodness-of-fit test to verify the probability distribution for empirical values (intensities of customer input flow – it means arrival rate and service time). Finally, the determination of the model M/M/n/∞. Such a system designation defines the exponential distribution of the input of the unit M, the exponential distribution of the service time M, the number of parallel service lines n with an infinite queue. Generalized Erlang formulas are used to calculate the probabilities of system statuses. We used Little’s law. The modeling was verified by simulation in Enterprise Dynamics simulation software. The results are identical [13, 19, 22, 23].

4. Results and Discussion

Simulation of regular operation, but also the crisis, was carried out based on data from experimental measurements performed at the post office in the residential part of the regional town (housing estate with a population of 12,547 inhabitants). The license for the provision of the universal postal service stipulates the obligation of the postal operator to ensure the availability of services to a certain extent, from local as well as time requirements [20, 24, 25]. According to the number of inhabitants, one post office has been set up in the settlement unit. On average, the post office serves approximately 18,500 customers per month. It handles an average of 28,520 registered requests (unrecorded customer requests are not included in this number), which represents approximately 1.54 requests per customer. The residential unit with modeled postal traffic has set opening hours for the public from 8.00 (8 am) to 18.00 (6 pm) during the working days and on days off from 8.00 (8 am) - 11.00 (11 am). The majority of the activities of the monitored postal establishment concern essential postal services, in particular the collection and provision of letter and parcel items as well as the provision of financial services. However, the post office also provides non-postal services and serves as the Integrated Service Point (IOMO) [17, 21].

4.1. Primary Research Implementation

The necessary activities for the implementation of modeling required:
• identification and analysis of the input flow of customers in the post office – arrival rate;
• identification and analysis of customer service time in the post office.
The properties and intensity of the input flow have a decisive influence on the operation of the Queueing theory...
and its essential characteristics. The input flow requests come to the operating system at random moments. The length of the interval between individual arrivals and service time represent the value of continuous random variables. The service life of customer requests is influenced by many random factors and is, therefore, also considered as a continuous random variable [13, 14].

**Analysis of the intensity of the input flow of customers and service time**

Based on a pilot measurement of the arrivals of customers and service time, number of classes and the interval length had been specified that had to be determined for processing the data obtained from the primary research.

Calculation of the number of classes for intensity of the input flow:

\[ k = 1 + 3.322 \cdot \log(n); \]

\[ k = 11. \]

Calculation of the interval length for intensity of the input flow:

\[ h = \frac{x_{\text{max}} - x_{\text{min}}}{k}; \]

\[ h = 0.5 \text{ minutes}. \]

Calculation of the number of classes for service time by (1): \( k = 7 \).
Calculation of the interval length for service time by (2): \( h = 1.5 \).

**Input data of primary research**

The input flow of customers is an essential random factor in the Queueing Systems. In the selected postal operation, the input flow is standard for 4 postal counters (service lines). All four counters are referred to as universal counters, thus providing complete services (they are equivalent). The IOMO service can be a specificity, which is provided only on one of the universal counters (it does not belong to the US portfolio); therefore, we did not take this specificity into account when modeling. We also ignored the predestination of the counter for parcel services, as this service is feasible for other counters as well.

The procedure for measuring the customer input flow for the selected postal office was as follows:

- In order to define the intensity of the input flow of customers at the post office, we performed six measurements on a sample of 1525 arrivals. The measured values are divided into time intervals calculated by pilot measurement. We assume that the measured empirical values correspond to an exponential distribution.

- Verification of exponential distribution by Chi-square test:

**Hypotheses determination:**

- \( H_0: \) The input flux intensity is controlled by the exponential distribution.
- \( H_1: \) Input flux intensity is not controlled by an exponential distribution.

**Determination of the test criterion:**

Calculation of theoretical probabilities:

\[ p_i = F(h_i) - F(a_i); \]

\[ p_i = 1 - e^{-\lambda h} - \left(1 - e^{-\lambda a}\right). \]

Calculation of average arrival rate (average customer flow):

\[ \lambda = \frac{1}{\bar{x}}, \]

while \( \bar{x} = 0.910655738 \) and therefore \( \lambda = 1.09 \) customer / minute.

To use the \( \chi^2 \) - test, the condition must be met: theoretical frequency \( (n*pi) \geq 5 \), for \( i = 1,2, ..., k \). In our case, it was necessary to merge the last two classes into one so that the theoretical frequency meet the requirement. For further assessment and illustration, we considered nine classes (see table) instead of the originally intended 11.

Calculation of test criterion:

\[ T = \sum_{i=1}^{k} \left( \frac{X_i - np_i}{np_i} \right)^2; \]

\[ T = 11.92503005 \]

**Determination of critical field:**
According to the tables for $\chi^2$ - distribution, we found the critical value of $\chi^2$ - distribution corresponding to the selected level of significance.

$$\chi^2_{0.05}(9) = 16.919$$

*The decision on the test result:*

We reject the tested hypothesis $H_0$ at the level of significance $\alpha$ if the calculated value of the statistic $\chi^2$ exceeds the critical value $\chi^2_{\alpha}$. Applies: test criterion value $<\text{critical value}$,

$$T < \chi^2_{0.05}$$

$$11.92503 < 16.919$$

This inequality is valid so we accept the null hypothesis. The intensity of the input flow of customers at the post office is led by the exponential distribution.

In the same way, it is necessary to verify the behaviour of the variable customer service time.

- The measured values of 731 times obtained from 5 measurements were sorted according to the determined intervals. Based on the obtained empirical values, we assume that the variable customer service time acquires an exponential distribution.
- Again, we will use the Chi-square test.

*Determination of the null hypothesis:*

- $H_0$: Customer service time is led by an exponential distribution.
- $H_1$: Customer service time is not led by an exponential distribution.

*Determination of the test criterion:*

Calculation of service rate:

$$\mu = \frac{1}{\lambda}$$

(7)

$$\mu = 0.432224686$$

Calculation of test criterion: $T = 4.75819$.

*Determination of critical field:*

According to the tables for $\chi^2$ - distribution, we found the critical value of $\chi^2$ - distribution corresponding to the selected level of significance:

$$\chi^2_{0.05}(7-1-1) = \chi^2_{0.05}(5) = 11.0705.$$ 

*The decision on the test result:*

$$T < \chi^2_{0.05}$$

$$4.75819 < 11.0705.$$ 

This inequality is valid so we accept the null hypothesis. The service time at the post office is led by the exponential distribution.

4.2. Determination of the Model for the Queueing System

According to Kendall's qualification of Queueing Systems, we classify a Queueing Systems with an infinite queue at the monitored post office. The gaps between the arrivals of customers at the post office are governed by the exponential distribution that is characteristic of Markov systems. To specify the model of the Queueing Systems, we specify:

1. **Service line network structure**
   The Queueing Systems of monitored post office represents a system of 4 independent parallel service lines.

2. **The intensity of the input flow of customers**
   The intensity of the input flow of customers (average arrival rate) at the post office is a stochastic process, which is described using a random variable. In our case, this corresponds to an exponential distribution of the length of time intervals between customer arrivals. Using the relationship between the exponential and Poisson distributions, we can determine the intensity of the input flow at the post office. Customers enter the multi-line Queueing system with a Poisson input flow with the parameter $\lambda = 1.09$ customer / minute.

3. **Mean service time**
   The mean customer service time has an exponential distribution with the parameter $\mu$. 
4. **The discipline of waiting in queue line**

Customers at the post office are served in the order in which they arrived, i.e. FIFO (first in - first out).

5. **Characteristics of M/M/n/∞ system**

The set of system states is \( S = \{1,2,3,...,n,\ldots\} \). The system is not stabilized if, on average, more customers arrive than the lines can serve. In order for the stability of system, the condition of system stabilization must apply: \( \lambda < n\mu \).

\[
\rho = \frac{\lambda}{n\mu} < 1 \quad \text{respectively} \quad \rho = \frac{\alpha}{n} < 1; \quad (8)
\]

\[0.625 < 1.\]

The system is stabilized t. j. on average, fewer customers enter the system than the post offices can serve.

As the Queueing Systems at the monitored post office is classified as a system with an infinite queue, the probability of customer rejection is zero. The researched characteristics are as follows (Table 1).

<table>
<thead>
<tr>
<th>System M/M/n/∞</th>
<th>Probability of rejection</th>
<th>( E(S) = \frac{1}{\mu} = \alpha )</th>
<th>(9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The average number of served customers in the system</td>
<td>( E(L) = \sum_{i=1}^{n} p_{i+1} )</td>
<td>(10)</td>
<td></td>
</tr>
<tr>
<td>The average number of customers waiting in a queue</td>
<td>( E(K) = E(S) + E(L) )</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>The average number of customers in the system</td>
<td>( E(W) = \frac{E(L)}{\lambda} )</td>
<td>(12)</td>
<td></td>
</tr>
<tr>
<td>Average queue time</td>
<td>( R = \rho )</td>
<td>(13)</td>
<td></td>
</tr>
</tbody>
</table>

The Table 2 presents the results of measured and simulated characteristics of the Queueing Systems in regular operation M/M/4/∞ or M/M/5/∞ with an input flow rate of 1.09 customers per minute, as well as in changed conditions caused by a crisis - loss of one service line M/M/3/∞, or the change in the intensity of the input flow (increase by 50%), which may be caused by a malfunction of another Queueing Systems or change of operating hours, etc.

<table>
<thead>
<tr>
<th>Number of service lines (postal counters)</th>
<th>Modelling of regular/standard situation</th>
<th>Crisis situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 service lines</td>
<td>5 service lines</td>
<td>3 service lines</td>
</tr>
<tr>
<td>( \lambda ) [customer per minutes]</td>
<td>1.09</td>
<td>1.09</td>
</tr>
<tr>
<td>( 1/\mu ) [customer per minutes]</td>
<td>2.31</td>
<td>2.31</td>
</tr>
<tr>
<td>( \alpha ) [customer]</td>
<td>2.52</td>
<td>2.52</td>
</tr>
<tr>
<td>( \rho )</td>
<td>0.63</td>
<td>0.5</td>
</tr>
<tr>
<td>( E(S) ) [customer]</td>
<td>2.52</td>
<td>2.52</td>
</tr>
<tr>
<td>( E(L) ) [customer]</td>
<td>0.78</td>
<td>0.13</td>
</tr>
<tr>
<td>( E(K) ) [customer]</td>
<td>3.06</td>
<td>2.63</td>
</tr>
<tr>
<td>( E(W) ) [in minutes]</td>
<td>0.51</td>
<td>0.12</td>
</tr>
<tr>
<td>( R ) [%]</td>
<td>63%</td>
<td>50%</td>
</tr>
</tbody>
</table>

The standard system status M/M/4/∞ (see column for 4 service lines in Table 2) shows the average number of served customers \( E(S) = 2.5 \) customers in the system. It represents system performance or the average number of busy lines. The system does not reject any customers; therefore, the average number of served customers can be expressed as the product of the intensity of customer flow (arrival rate) and the average service time. The average number of customers waiting in queue \( E(L) = 0.56 \) customers and the average number of customers in the system is 3.06
customers. The current system setup situation corresponds very well to the licensing requirements because the average waiting time in queue $E(W) = 0.51$ minutes/customer. The universal postal service provider is obliged to minimize the waiting time at each post office so that the average waiting time at the post office box does not exceed 12 minutes. The use of the system $R$ represents a percentage expression of the value of $\rho$. The stochastic Queueing Systems cannot be used in 100%. If the system were 100% used, i.e., $\rho = 1$, the system would never be empty at one time. In the current state (standard situation), the system is used at $R = 63\%$. For practical reasons, a traffic intensity of more than 0.8 is not recommended. For high values of traffic intensity, the time for which the request must wait in a row and, of course, the length of the row, increases significantly.

If we change the number of service lines in the system in order to optimize it, it is possible to consider reducing the number of counters from 4 to 3 in order to maintain a stabilized system (see column for 3 service lines in Table 2). This means that the system will still be able to serve incoming customers. However, if we were to solve a change in conditions with a worsened operating condition, e.g., $M/M/3/\infty$ while maintaining the intensity of the input flow, the system is still stabilized. However, the average number of customers in the system will increase from 3.06 to 5.8, which means that the creation of a queue (waiting for service) will gain more significant parameters. However, it is still acceptable concerning the standardized quality requirements (12 min.), since $E(W) = 3.03$ min/customer. The system works in a ratio of 83%. As already mentioned, the theoretical recommended limit is an intensity of 0.8 and thus, the system acquires limit but acceptable values.

In the analyzed system, it is not necessary to consider increasing the number of lines, but for clarity, we present the results. The $M/M/5/\infty$ system will be used to 50%, with almost no customers in the queue (0.13 customers) and only 2.63 customers in the system with three functional counters. The system is starting to appear inefficient with significant reserves.

If the system is modeled as $M/M/4/\infty$ but with increased intensity by 50%, the system will be stabilized; however, the waiting time will increase to 10.36 min/customer and the average number of customers in the system will be 20.74 and the average number of customers in the queue will grow to 16.94 customers. The system has an intensity of 0.95, which means that insufficient reserves are created for smooth operation. The system is overloaded. This is a crisis condition that must be addressed.

5. Conclusion

Modeling queueing systems and simulating their behavior brings for the operators many essential insights. The current situation shows us that this is a way to obtain information that can play an important role in crisis management to ensure the provision of services of adequate quality. The data obtained by simulating postal traffic can also be used for optimization purposes, not only in terms of the total number of counters but also in setting the work changes of employees operating the counters during the day. A detailed analysis of flows in individual parts of the day can demonstrate the occupancy of lines as well as the effectiveness of opening hours in individual parts of the day. The simulations thus provide a primary basis for information for creating reserves in the system in case of an acute need for a change of the system of work.

Acknowledgement

VEGA 1/0152/18 Business models and platforms in digital space.

VEGA 1/0721/18 The research of economic impacts of visual smog on transport using methods of neuroscience.

References

192: 130-135.


The Local Cooling System for the Valve Unit of Automotive Diesel Engines

O. Trynov¹, D. Sivykh²

¹National Technical University “Kharkiv Polytechnic Institute”, Olimpiiska 25, 61060, Kharkiv, Ukraine,
E-mail: trinaleksandr427@gmail.com
²National Technical University “Kharkiv Polytechnic Institute”, Valentynivska 44, 61121, Kharkiv, Ukraine,
E-mail: sivikh1979@gmail.com

Abstract

The results for calculation and experimental research of the thermal state of the details of a discharge valve unit of motor-and-tractor type high-speed diesel are represented. It is suggested to apply local cooling of the details with compressed air at particular the most heat density regimes to improve the thermal state of the unit. The heat density regime rate shall be defined under the temperature of exit gases at the diesel engine discharge. Freezer submission control shall be performed in an automatic regime. Critical temperatures of exit gases shall be entered into the local cooling control system program. The system working capacity has been conducted during an engineless experiment with the evaluation of the efficiency under the temperature decrease velocity of the unit details and the relevant additional energy consumption. Practical use of the valve unit local cooling control system is considered the most attractive for diesel power plants with the forcing level under liter capacity over 20 kW per litre, particularly on heavy goods vehicle diesel engines.

KEY WORDS: valve, seating, socket, cooling, thermal state, heat density, automatic control, automotive diesel engines

1. Introduction

Raising the level of boosting to contemporary automotive diesel engines to improve their economic parameters is followed by an increase in combustion intensity, including but not limited to the discharge valve unit’s elements (the valve, its nozzle and guide). These elements, while on the run, are characterized by a limited amount of heat taken away by the cooling system. So, to secure their reliable performance, additional measures must be articulated to stimulate this heat removal.

The ICE Department of National Technical University “Kharkiv Polytechnic Institute” conducted a long-term calculated and experimental study into the stressed state of the valve unit elements in a high-speed diesel engine of the type 4ChN12/14 under conditions of local cooling by compressed air. At the same time, an assessment was made of the effectiveness of constructive suggestions to the accomplished reduction of temperatures in the valve, seat and guide as well as to the temperature reduction rate from the moment when the compressed air as a coolant was delivered, depending upon the air excess pressure. To calculate energy costs associated with the operation of the local cooling system (LCS), the coolant-flow rate under all operating conditions was determined as well.

For energy costs in diesel engines to be reduced, it is suggested that a local cooling system be developed where provisions are made for automatic control over processes of coolant admission in the function of the level of thermal stresses associated with the engine operating condition. Such a level is specified according to the temperature of exhaust gases as they leave the engine. It will likely be possible to practically implement an LCS system on the basis of power units without introducing significant changes into the structural design of basic parts of series-produced engines. It is suggested that conventional piston-type compressors be used as a source of compressed air. A reserve of compressed air under excess pressure of up to 1MPa shall be kept in pressure vessels and consumed under critical conditions to cool the valve unit elements.

For example, heavy duty vehicles may be taken as such power units whose physical data are the fittest to accommodate elements of the LCS system. To this date, according to a preliminary analysis, the best known producers of such vehicles are as follows: Tatra, Scania, Volvo, and MAN. These vehicles are set in motion through the use of a four stroke-cycle diesel engine whose liter capacity is between 25 kW and 30 kW per litre, with the level of boosting across the mean effective pressure being in the range of 1.2 MPa to 2.0 MPa.

A high level of boosting to such engines for the sake of their reliable operation requires that further structural provisions be made to increase their reliability and service hours.

2. Topicality of the Study and Statement of the Problem

Considering a further increase in the level of boosting to automotive diesel engines, which is touted as a steady trend, and paying attention to a rise in thermal stresses of the valve unit elements alongside with the strengthened reliability-related requirements, the current interest is focused on analysis into the working efficiency of automatic control systems meant for governing the thermal state (ACSTS) of the valve unit elements under conditions of local
cooling.

The undertaken study posed and addressed the following challenges:
- to assess the efficiency of local cooling to individual parts of the discharge valve unit with respective energy costs taken into account;
- to develop an ACSTS and a control program, to select actuating elements;
- to practically verify the functionality of the ACSTS of the valve unit.

3. Study Results

The effectiveness of the valve unit’s local cooling was assessed in the course of engine-based and engineless experiments. Following on from the results of the experimental stage, a mathematical model was refined for heat-stressed conditions of the valve unit and its elements. This mathematical model was developed on a finite-element basis. To solve the problem of heat conduction, use was made of boundary conditions related to the second and third types [1].

The hottest part of the valve unit is the valve itself, predominantly its disc running under conditions of limited heat removal. Because of this, the effectiveness of the LCS of the valve unit can be accessed on the basis of variations in the valve’s thermal state. The following methods of delivering the coolant and of improving the thermal state of the discharge valve become a possibility:

a. the coolant is fed directly to the discharge valve;
b. the coolant is fed simultaneously to the valve and the seat;
c. the coolant is fed simultaneously to the valve and the guide;
d. the coolant is fed to the valve seat and the guide.

In the course of the early undertaken engine-based and engineless experiments, there were practically implemented some cooling options for each element in isolation from one another. The experiments were accompanied by measuring the heat flow in the valve element and the air consumption [1]. Based on the experimental data, mathematical models of heat-stressed conditions were worked out and refined for each of the above elements. A calculated model-based analysis into a two-circuit cooling system (options b, c) and a three-circuit cooling system (options d) involved taking into account the operation of an individual circuit with its impact upon a change in temperature of the valve disk by adjusting respective boundary conditions in the areas where the discharge valve is in contact with the guide or seat. The coolant consumption for the two-circuit and three-circuit cooling systems was determined as a total of respective one-circuit flow rates. The cooled discharge valve (option b) is fitted with a flow-through cavity. For all options, the rated operating conditions of a diesel engine of the type 4ChN12/14 ($N_e = 73.6$ kW, $n = 1800$ min$^{-1}$) were simulated. The excessive pressure of cooling air was taken as being equal to 0.1 MPa, the same as for the experiments. For comparison, Fig. 1 shows the temperature pattern of a production-standard valve (option a) under the design conditions.

Fig. 1 Thermal state of the production-standard valve (a) and the valves (b, c, d) meant for cooling systems a, b, c.
The flow rates of cooling air, as obtained in the engine-based and engineless experiments under the pressure $P_a = 0.10\ldots0.15$ MPa, made up the following values while cooling:
- for the valve 4.64 m$^3$/h;
- for the seat 3.5 m$^3$/h;
- for the guide 6.4 m$^3$/h.

For example, in the event that only the valve is being cooled, the energy consumption increases by 2.04 kW [1].

With the view of upgrading the system of local cooling to the valve and to the area of inter valve jumper, the ICE Department conducted engineless experiments on a fragment of the blockhead of the 4ChN12/14 diesel engine and on an individual cylinder head of the KAMAZ-740 diesel engine. There was performed simulation of surface heating in the blockhead’s end plate and of the local air cooling to the seat area. The coolant pressure varied between 0.1 MPa and 0.3 MPa, and the air consumption varied between 4.5 m$^3$/h and 5.4 m$^3$/h. The fall in temperature of the valve seat area and in temperature of the chamfered edge itself of the uncooled valve was in the range of 100°C to 140°C [2, 3].

Taking into account the results of the undertaken calculated and experimental study, and considering the complexity of required structural alterations to be introduced into the valve unit and the cylinder head, the two-circuit system under option b is touted as being the most promising. With that, a provision is made, depending upon thermal conditions (controlled according to the temperature of exhaust gases) for a phase-by-phase delivery of the coolant firstly to the valve seat and then, if required, to the discharge valve itself. The critical temperatures of exhaust gases for each diesel engine are specified and selected on the basis of results of the engine-based experiments.

Fig. 2 shows the developed system which was experimentally tested on an engineless bench. The target of study was the KAMAZ diesel’s cylinder head which is fitted with thermo-electric couples and contains channels for local cooling adjusted by a microprocessor-based system. With power on, the air regulator 9 is set into the totally closed position. At the moments of open/close operation, a green light-emitting diode HL1 or a red light-emitting diode HL2 is switched on. In extreme positions (totally open/close operation), a respective LED illuminates on a continuous basis. With the air regulator being set into its initial position, the temperature check begins by measuring the temperature with the help of the thermo-electric couple 11. When the selected boundary temperature is exceeded, the air regulator is opening, and the air is delivered to the discharge valve seat. The air regulator will be kept in the open position until the temperature gets smaller than the selected boundary temperature. In the meantime, the air pressure in the delivery system will be constantly controlled by means of the sensor 13. If the pressure drops below the critical value, the air regulator will be closed until the receiver 5 is filled up and the pressure is restored, at which point the temperature check will resume.

With the air regulator being in the open position, the possibility exists that it can be forcibly closed (the push button S2) and kept in such a position for 30 seconds. Once this is done, the algorithm for temperature checking will
resume. If the temperature measured by the thermo-electric couple $I$ is not in excess of the selected temperature, a provision is made for the air regulator to open (the push button S1). The air regulator can be kept in the open position for 30 seconds only. The push button S3 allows for making adjustments to the air regulator’s travel. In order to come over to these adjustments, it is necessary to push the button S3 and keep it pressed until the adjustments end up. These adjustments are carried out in relation to the totally closed state; so if the air regulator is open at the moment when the push button S3 is being pressed, this regulator will be closed. The transition to the adjustment mode is indicated by LEDs HL1 and HL2 that simultaneously switch on. Such adjustments are required to regulate the leak proof seating of the valve $a$ after the air regulator has been installed. The liquid-crystal display $I_6$ is able to show information about the air pressure and temperature in the expansion chamber 7, about the temperature in the checkpoint of the discharge valve seat as well as about the time to the opening (the closing) of the air regulator. The control system is materialized on the basis of the Atmel-made microcontroller ATmega16 [4] which operates at the timing frequency of 8 MHz. The external power supply voltage of $+12$ V is stabilized by the LM1815 [5] microcircuit chip at the level of $+5$ V to ensure that the power is supplied to all parts.

For a primary transducer of temperature during the engineless experiment, use was made of a Cr/Al thermocouple whose thermo-EMF is enhanced by an operating amplifier. This amplifier is designed to measure temperatures of up to $1000\,^0C$. Then the enhanced signal is fed to the input of an internal AD converter (ADC) of the microcontroller. The ADC is set to operate in the 10-bit mode. The reference voltage of $+5$ V comes to a respective input of the microcontroller from the voltage stabilizer. The temperature accuracy, as assured by the ADC channel with due regard for calibration tolerances, is no more than 2.5 $^0C$. The microcontroller runs the program from an internal flash-memory drive. According to the thermocouple’s readings, the signals that activate the air regulator appear on the output port’s lines. For the air regulator 9, use was made of a commercial engine idler which is used in ICE integrated control systems of the VAZ family (Fig. 3). This component is materialized on the basis of a stepping motor where the discrete shaft rotation is translated through a feed nut assembly into the progressive advance of a shut-off nose-piece.

To ensure the stepping motor’s behavior, use was made of a controller based on microcircuit chips L297 [6] and L298 [7]. The chip L297 contains a time sequence logic and makes it possible to control the start and shutdown of the stepping electric motor as well as its shaft’s r.p.m. and rotation sense. In this case the chip L298 performs the function of a shaper producing an output control pulse of sufficient power to activate the stepping electric motor.

All necessary information is transmitted through serial exchange lines of the UART microcontroller and the MCP2200 [8] – based interface converter to the USB port of the notebook computer. Each parcel incorporates the following parameters: the current time, the output voltage from the amplifier of thermocouple’s signals, the temperature being measured, and the air regulator’s state (0 = closed, 1 = open). For further processing, these data are saved on the computer’s hard disk in the form of a text file. The system functionality and the execution of the preprogrammed algorithm were pre-tested with the use of boiling liquids and engine oils. So, while pre-testing in the heated engine oil, the air regulator’s opening temperature was set to $150\,^0C$ and its closing temperature to $100\,^0C$. An analysis of the data transmitted by the microprocessor-based system revealed a smooth rise in the voltage (temperature) at the output from the amplifier and the well-timed (at $153.7^0C$) opening of the air regulator. When the oil got slowly cooled the air regulator closed at $99.2\,^0C$. As a result of this pre-testing, it was found that the measurement error fell inside the limits of $\pm 2.5\%$, while the operation algorithm of the microprocessor-based system was executed in a fail-safe manner for the set boundary values of temperature.

The next step in the pre-testing of the ACSTS functionality involved an engineless experiment as such, where the receiver was fed with the boundary values of temperature and pressure for the air regulators On or OFF operations. Fig. 4 is illustrative of how signals from the press/temp sensors vary with time, where the time intervals (289–326 s, 356–373 s) are marked in conformity with the air regulator’s open position. This graph is plotted upon information saved on the computer’s hard disk in the form of a text file.

In the meantime, the moment, when the cooling air is open to be delivered for this test case, is set at $150\,^0C$ (289 s), while the moment, when this delivery is cut off, is set at the temperature fall to $80\,^0C$ (326 s). Once the pressure in the receiver becomes lower than $150$ kPa, the air delivery ceases at any temperature, and the compressor turns on to pump the receiver.
4. Conclusions

The undertaken calculated and experimental study has shown the possibility that automatic control may be exercised over a local cooling system of the valve unit for pre-programmed critical temperatures of the unit’s elements, with these temperatures being specific to engines with high levels of boosting.

The developed automatic control system for governing the thermal state of the valve unit elements (ACSTS) has confirmed its working efficiency and reliability under conditions of engineless experiments. The attained results will be used as part of the preparation for engine-based experiments, where the temperature of exhaust gases and the pressure of cooling air in the receiver are seen as the setting parameters to be controlled and kept track of.

References:

Research of the Rocket Target Airframe Strength Characteristics

A. Fedaravičius¹, K. Petkevičius², K. Pilkauskas³, A. Keršys⁴, A. Survila⁵

¹Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: algimantas.fedaravicius@ktu.lt
²Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: kazimieras.petkevicius@ktu.lt
³Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: kestutis.pilkauskas@ktu.lt
⁴Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: arturas.kersys@ktu.lt
⁵Kaunas University of Technology, Studentų 54, 51424 Kaunas, Lithuania, E-mail: arvydas.survila@ktu.lt

Abstract

Strength analysis of the rocket body and flight stabilization wings made of aluminium alloy and fiberglass under aerodynamic loads was carried out. Pressure distribution on the surface of the rocket body and in the axial section at the maximum planned target flight speed was determined by the method of numerical analysis. By FEM using shell elements, the distribution of von Misses stresses at different time instants was determined. A comparative analysis of the obtained results was performed and the material for flight stabilization wings was selected.

KEY WORDS: rocket target, body, flight stabilization wings, aerodynamic load, strength

1. Introduction

Rockets differ from other air vehicles, such as military aircraft, in their functions and technical parameters. Rockets are unmanned aerial vehicles. Therefore, their trajectory and flight dynamics may be steeper causing significantly higher overloads. Their lateral and longitudinal accelerations can reach up to 30g. The speed of rockets usually is higher than that of military aircraft. Other differences are the higher dynamic pressure on the rocket body at their relatively low mass [1, 2].

Important technical parameters [3] of the rocket defining its flight characteristics are airflow characteristics due to angle of attack, Mach number, flight altitude, fuselage front configuration, diameter, propellant type and mass, wing geometry and size, stabilizer geometry and size, geometry and size aerodynamic steering wings, variation in traction.

The airframe of the rocket body in which all its components are mounted must be resistant during all phases of flight. Another important condition is the minimum weight of the airframe. Therefore, the structure of the airframe must be optimal - light and sufficiently durable. The resistance of the structure, in this case, is defined by its strength, stiffness and stability [4].

2. Analysis of the Loads and Stresses in the Airframe

Two variants of the airframe design are considered for the analysis of aerodynamic loads and stresses of the rocket target:

a) the cylindrical part is made of aluminium alloy:
   - external diameter - 400 mm;
   - thickness of the wall – 5 mm.

b) the cylindrical part is made of a laminated composite material:
   - external diameter – 400 mm;
   - the wall is wrapped in three layers;
   - glass-fiber plastic: (thickness – 2 mm, reinforcement ratio – 0.5, fiber orientation – 45 degrees).

Fig. 1 Diagram of loads acting on the rocket during flight
The loads acting on the rocket during the flight are shown in Fig. 1, here \( v \) - flight velocity; \( \alpha \) – the angle of attack; \( q_a \) - aerodynamic pressure; \( q_m \) - gravitational load; \( Q \) - traction force; \( R \) - aerodynamic force acting on the stabilizer.

2.1. Aerodynamic Pressure on the Airframe

The aerodynamic pressure acting on the rocket body depends on the angle of attack and the Reynolds number. Pressure distribution at steady state, at different angles of attack and flow velocity \( v = 200 \, \text{m/s} \) is shown in Figs. 2-3.

![Fig. 2](image1.png)

**Fig. 2** Aerodynamic pressure on rocket body at flight velocity 200 m/s and angle of attack – 0 degrees: a – pressure distribution on the surface; b – pressure distribution in the axial section

![Fig. 3](image2.png)

**Fig. 3** Aerodynamic pressure on rocket body at flight velocity 200 m/s and angle of attack – 45 degrees: a – pressure distribution on the surface; b – pressure distribution in the axial section

2.2. Variation of Stresses in the Rocket Body on its Trajectory

Stress analysis was performed using a shell finite element model and explicit integration [5, 6] in the selected segment of the trajectory, motion duration along which is 3 s. Analysis of the variation of the body stress in motion along the trajectory was performed.

2.2.1. Aluminum Alloy Body

The determined distribution of von Misses stresses in the rocket body at different time instants is presented in Fig. 4 and the time dependences of the stresses in all elements of the body are shown in Fig. 5.

2.2.2. Laminate (Layered) Composite Body

Distribution of von Misses stresses in the fiberglass layers of the body elements at different time instants presented in Fig. 6. The dependences of von Misses stresses on the time in the fiberglass layers of the body elements are shown in Fig. 7.
Fig. 4 Distribution of von Misses Stresses in aluminium body of the rocket: a $- t = 0.15 \text{ s}$; b $- t = 3.0 \text{ s}$

Fig. 5 Dependences of von Misses stresses (Pa) on time (s) in all elements of the aluminium body

Fig. 6 Distribution of von Misses stresses in the composite material rocket body: a $- t = 0.15 \text{ s}$; b $- t = 3.0 \text{ s}$

Fig. 7 Dependences of von Misses stresses (Pa) on time (s) in all elements of the composite material body

The comparative analysis of the rocket body resistance is intended for preliminary evaluation of stresses acting
in flight. The stress states in the selected trajectory range were compared for the two variants of the rocket structure:
- with aluminium alloy body;
- with a laminate (layered) composite body.

The stress state was analysed in 3-second trajectory section at an initial speed of 140 m/s. The calculations were performed using a shell finite element model and explicit integration. The maximum von Misses stresses in the aluminium alloy rocket body do not exceed 8 MPa.

Maximum von Misses stresses in the fiberglass layers of the composite material body do not exceed 5 MPa. The maximum tangential stresses in the honeycomb layer are less than 5 kPa.

These results of stress analysis in the rocket body show that in both cases of the examined design variants the maximum stresses are much lower than the yield and strength limits of the materials. In the case of such a stress state, no signs of instability in the structure of the materials were observed.

In the current analysis, it was assumed that the layers are bonded and no slip between them is possible. It should be noted that the strength of the laminate (layered material) is highly dependent on the adhesive properties of the layers, therefore, special attention must be paid to the quality of the rocket body wrapping process.

Based on the performed aerodynamic flow analysis and resistance tests of the rocket body and taking into account lower economic costs, a fiberglass composite material was selected for the rocket body with an elliptical front configuration.

3. Evaluation of Structural Strength of the Assembly Unit of the Rocket Motor Attachment and the Structure of Stabilizers

When developing the design structure of the rocket target, it is very important to ensure the strength of the design of the motor attachment unit and the structure of rocket flight stabilizers in case of static and dynamic loading.

In the first stage, the aerodynamic load acting on the rocket motor attachment unit and the stabilizers structure was determined for the set rocket flight velocity and motor thrust force values. The stabilizers in the analysed structure are made of a 4 mm thick aluminium-alloy plate (Fig. 8), and the rocket body is made of 3 mm thickness wrapped fiberglass.

![Fig. 8 Schematic of the connection of the stabilizer and the plane of the motor attachment unit](image)

Loads acting in the system are assumed as:
- thrust force of the rocket motor is 10 kN;
- pressure distribution of the stabilizer's wings is even.

Then the forces acting on stabilization elements are:

\[ q_a = C_L \frac{\rho v^2}{2} = 0.5 \frac{1.25 \cdot 250^2}{2} \approx 20 \text{ kPa} , \]  

where \( C_L \) – lifting force coefficient, \( \rho \) – air density \( (h = 0 \text{ m}) \), kg/m\(^3\), \( v \) – flight velocity of the rocket, m/s.

The schematic of aerodynamic pressure distribution on stabilization wings is shown in Fig. 9.

![Fig. 9 Schematic of aerodynamic pressure distribution](image)

The analysis of the stress strains state was performed, the results of which are presented in Fig. 10.
The analysis of the obtained test results showed that at the assumed uniform aerodynamic pressure of 20 kPa, the maximum stresses in the stabilizer do not exceed 50 MPa, in the rocket body - 100 MPa, and the maximum deflections of the stabilizers do not exceed 30 mm.

Therefore, it can be stated that according to the results of the analysis, the strength of the motor attachment unit and the structure of stabilizers is sufficient. This was also confirmed by field-experimental tests and an investigation of the operation of the developed rocket targets.

4. Conclusions

Investigation of the strength of the rocket body and flight stabilization wings made of aluminum alloy and fiberglass under aerodynamic loads was conducted. By the method of numerical modelling, pressure distribution on the surface of the rocket body and in the axial section at the maximum intended velocity of the target flight of 200 m/s was determined. By FEM using shell elements, the distribution of von Misses stresses at different time instants was determined, which showed that von Misses stresses in the layers of glass fibre composite do not exceed 5 MPa and the maximum tangential stresses in a honeycomb layer are less than 5 kPa. In case of such a stress state, no signs of instability in the structure of the material were observed, therefore, based on the performed aerodynamic flow analysis and resistance tests of the rocket body and taking into account lower economic costs, a fiberglass composite material was selected for the rocket body with an elliptical front configuration.

It was determined that at the assumed uniform aerodynamic pressure of 20 kPa, the maximum stresses in the stabilizer do not exceed 50 MPa, in the rocket body - 100 MPa, and the maximum deflections of the stabilizers do not exceed 30 mm, therefore it can be stated that strength of the motor attachment unit and the structure of stabilizers is sufficient.

Acknowledgement

This work was supported by the Research Council of Lithuania, grant No. S-MIP-17-94 „Experimental Rocket: Research and Development“.

References

Audit of Passenger Information Signs on Poznań Główny Railway Station

A. Strażko¹, P. Smoczyński², A. Gill³

¹Poznan University of Technology, pl. Marii Skłodowskiej-Curie 5, 60-965 Poznań, Poland
²Poznan University of Technology, pl. Marii Skłodowskiej-Curie 5, 60-965 Poznań, Poland,
E-mail: piotr.smoczyński@put.poznan.pl
³Poznan University of Technology, pl. Marii Skłodowskiej-Curie 5, 60-965 Poznań, Poland,
E-mail: adrian.gill@put.poznan.pl

Abstract

For several years, a systematic increase in the number of passengers transported by trains has been achieved in Poland, which translates into the number of people using railway stations and stops. One of the largest stations in Poland is the Poznań Główny station in the western part of the country. Unfortunately, as a result of investment works, the readability of the station was seriously disturbed, which causes passengers confusion and many problems with finding the way to the platforms. The article presents selected fragments of the audit carried out at the station, aimed at verifying the correctness and legibility of the signs that direct to platforms. The problems identified concern both the lack of signs and the lack of clarity in the information provided.

KEY WORDS: information system, compliance, railway infrastructure

1. Introduction

For several years, a systematic increase in the number of passengers transported by trains has been achieved in Poland. This translates into the number of people using stations and railway stops. As of 2017, the Poznań Główny railway station is the second largest station in the country. The average number of passengers per day is almost 53 thousand, and on an annual basis – over 19 million. About 360 trains a day stop at the main station in Poznań, and the average passenger exchange per train is about 150 passengers [4].

The increasing number of passengers, as well as image issues and the increasing level of aesthetic and functional requirements are the reasons to rebuild and expand station buildings. Unfortunately, in the case of Poznań, this process led to the creation of a set of non-integrated elements, among which one can distinguish: New (Station) Building, Old Building, West Building, Summer Building as well as platforms and areas around the station. As the New Building was opened in 2012 in connection with the football tournament, it was decided to close the centrally located historic Old Building in 2013. The remaining objects, scattered over a fairly large space, in many cases cause a sense of chaos and confusion. Passengers seek help in finding platforms that interest them, among others at InfoDworzec information point, where the first author of this publication worked.

Taking up the subject of correctness and meaningfulness of information signs at Poznań Główny station was inspired by the experience gained from work at the InfoDworzec point, however, it is in line with the research in the field of wayfinding and architectural design conducted worldwide [5]. The aim of the article is to present selected fragments of the audit. Section 2 describes the Poznań Główny station and shows how a test sample, i.e. scenario of passage between platforms, was selected. Section 3 contains commented photographic material that was collected during the audit. Discussion and conclusions are included in section 4.

2. Materials and Methods

2.1. Area of Poznań Główny Railway Station

Poznań Główny railway station is located in the central part of the city of Poznań. There are 4 buildings related to passenger service at the station: New Building, Old Building, West Building and Summer Building. From 1879 to 2013, travellers at the Poznań Główny station were served in the Old Building, while from 2013 the New Building connected with a shopping mall was opened and became the main passenger service facility to this day. The New Building and the West Building are connected by an underground tunnel. The Summer Building, on the other hand, is connected to the New Building by a ground passage; in order to get to the West Building, both ground and underground passage has to be taken. The Old Building is currently used as a place to periodically organise cultural and social events.

The Old Building is located in the central point of the train station, which made it easier for passengers to reach the platforms. On one side there were platforms 1, 1a, 2, 2a and 3, and on the other side of the station 4, 4a, 4b, 5 and 6. New Building is located so that it has direct exits to platforms 1, 2, 3, and other platforms can be reached either via a ground passage (platform 4) or via an underground tunnel (platforms 5-6) – see also Fig. 1.

The location of the currently functioning New Building leads to confusion among passengers. Seeing only exits to
platforms 1-3 they are not able to quickly find platforms 4-6 that interest them. This often leads to the loss of a further train connection by travellers, because during the time they had to change they did not manage to find the platform from which their next train left.

2.2. Auditing Method

An audit can be described as an independent, objective and systematic activity which purpose is to check the financial, organisational and management systems of a given enterprise, organisation or entity. Obtained audit results are aimed at improving the functioning of a given organisation in the examined aspects [1, 2].

In practice, it is usually unreasonable to audit the entire subject matter; conclusions are drawn on the basis of randomly selected samples (documents, technical objects, processes, etc.). In the case of a large railway station, such as the Poznań Główny station considered here, it is also reasonable to select and evaluate only some elements of the passenger information system. In order for this choice to reflect the real problems of passengers as much as possible, it was decided to focus the audit around the scenarios of changing platforms on the station.

The audit concerned signs that guide the access to platforms at the Poznań Główny station. The verification covered the fact whether the marking is understandable and whether it allows passengers to reach selected platforms. Performing the audit consisted of moving from one point of the station to another and documenting the transition using photos and diagrams. The audit results were referred to the provisions of the permanent marking guidelines at the passenger station, applicable at railway stations on the network of PKP Polskie Linie Kolejowe S.A., Polish state-owned railway infrastructure manager [3].

2.3. Scenario Selection

The scenarios were identified on the basis of a list of problems reported at InfoDworzec, located at the New Building. In the period from October 22 to November 30, 2019, at selected periods during the opening hours, i.e. between 07:00 and 21:00, a systematic recording of problems reported by passengers was carried out. The total study time was 112 hours. The method of conducting the study was to talk to the passenger during their visit at the railway information point. When the passenger asked about reaching the platform of interest to them, such information was recorded in the table.

After completing the study, all results were transferred to a spreadsheet to summarise the information obtained. On this basis, it was confirmed that passengers have a problem with reaching platforms whose exits and entrances are not directly connected to the New Building. With finding platforms 1, 1a, 2, 2a and 3, passengers do not have much difficulty, because the exits to them are in the main hall. On the other hand, platforms 4, 4a, 4b, 5 and 6 are located outside the New Building, which confuses travellers. There were also numerous complaints and comments to InfoDworzec information point regarding the signs used to guide to the platforms, their readability and correctness of information given. Travellers say that the signs is not understandable for everyone to quickly reach the platform they are looking for.

Based on the analysis of the information obtained, audit scenarios were selected, including the scenario described in this article: involving the transition from platform 3 to platform 4b (i.e. the Summer Building) with a stroller. As platform 3 is the far-most platform, the selected scenario allows for generalisation of results also for other platforms located under the New Building. In addition, the study covered the question of whether a passenger with reduced mobility (with a stroller) is able to reach a distant platform using all the facilities at the station.

3. Audit of Passage with a Stroller from Platform 3 to Platform 4b

The scenario being the subject of the described part of the audit assumes the transition from platform 3 to platform 4b, located near the Summer Building. There are several alternative options for making this transition; in particular, it is possible to take the route through the tunnel under the Old Building or through the hall of the New Building. The study assumed that the passenger chose the second option, and the entire route was divided into 5 stages:

1. Entrance to the New Building
2. Passage through the New Building
3. Exit from the New Building
4. Crossing the station square
5. Passage along the tracks to platform 4b.

The selected route is schematically shown in Fig. 1.

The relatively simplest stage is the entrance to the New Building. Passenger information signs on platform 3 correctly direct passengers to the elevator enabling entry to the main hall (Fig. 2).

In New Building, information signs regarding access to platforms are placed above the exits to platforms and on information pillars (signposts in the form of arrows). It is worth noting that both types of boards use a shortened record of platform markings (e.g. ‘4b-6’), as well as the distinction between platform 4b and the Summer Building [Dworzec Letnii] (Fig. 3).

Then, after leaving the New Building by the elevator at platform 1, there is an information board indicating the direction in which it is necessary to go to reach platform 4b (Fig. 4). After following the directions to the pedestrian crossing, it is not possible to specify exactly which way to go, because there is no sign that would inform about it, and the sign on the other side of the station square is invisible (Fig. 5).
Fig. 1 Diagram of the audited route from platform 3 to platform 4b

Fig. 2 Sign for access to elevator on platform 3

Fig. 3 Signs for access to platforms at the end of the main hall in the New Building: a – sign above the exit to platform 1; b – signpost at the end of the station hall

Fig. 4 Information sign located by the elevator on platform 1

Fig. 5 An invisible information sign on the other side of the station square
After passing the square and approaching the information sign mounted there, it can be read that it indicates the direction in which platform 4b is located. The last stage is the transition from this sign to platform 4b along the tracks. The platform is easy to find, but there is no way to confirm its number, as there are no information signs that would inform about it (Fig. 6).

![Fig. 6 No information signs with number on platform 4b](image)

4. Discussion and Conclusions

An audit of selected elements of the passenger information system at the Poznań Główny station has shown that the signs at the station require some changes. The introduction of these changes is aimed at improving the operation of the station. Audit results confirmed passengers’ opinions regarding platform signs – that they are incomprehensible and illegible, and above all – not compliant with requirements [3]. These requirements include such issues as:

- information should be provided mainly by means of arrows and pictograms, where necessary such information should be supplemented with text;
- signs at the entrance to the platform should enable passengers who enter this platform to make sure that they are going to the correct platform and information about track numbers should also be included;
- on boards that lead to two platforms next to each other, the numbers of these platforms should be given after the coma, e.g. platforms 1, 2;
- in the event that the boards direct to more than two platforms with consecutive numbers, extreme numbers separated by a dash should be given, e.g. platforms 4-6.

Regarding the audit results, two basic problems can be distinguished: lack of signs and incomprehensible signs. The first of these is more objective. First of all, there is no sign at the pedestrian crossing through the station square. After leaving the elevator on platform 1 and going in the direction pointing through the information sign placed there (Fig. 4), the traveller does not find any additional information that would indicate the necessity to cross the square, which may extend the time needed to get to the platform 4b and in case of a short transfer time may lead to loss of train connection. The sign leading to the platform 4b located on the other side of the station square (Fig. 5) is too far for the passenger to see and read easily what is written on it. Secondly, there is no marking on platform 4b confirming that it actually is platform 4b (Fig. 6).

In the area of incomprehensibility, inconsistent joint markings of platforms should be indicated. On the signpost located at the end of the station hall in the New Building (Fig. 3, b) the direction of passage to platforms 4-6 is marked as ‘4, 4a, 4b-6’, while above the exit to platform 1 (Fig. 3, a) access to platforms 4-6 is marked ”4, 4a-6”, and platform 4b is marked separately. The platform notation on the signpost suggests that platforms 4b, 5 and 6 are located next to each other. However, the information sign above the exit to platform 1 excludes the location of platform 4b in the vicinity of platforms 5 and 6 and indicates that it is in a completely different direction. In reality, platforms 4, 5 and 6 are next to each other at the station, while platform 4a and platform 4b are located at opposite ends of the station. As a result, the information provided by the signs in question incorrectly inform passengers about the real location of platforms 4a and 4b.

The conclusions of the audits carried out were forwarded to those responsible for signs at the Poznań Główny station and were met with great interest. It gives hope for gradual improvement of the information system and also shows the legitimacy of undertaking this type of research. In the future, it would be worth extending the audit to other railway stations and stops, which would facilitate the generalisation of the adopted method and, as a consequence, the increase in the reliability of the results obtained.

Acknowledgements

The research work was financed with the budget subsidy for support and development of research potential for the Faculty of Civil and Transport Engineering at the Poznan University of Technology.
References

Assessment of the Impact of Road Transport Enterprise Technological Development on Arranging of Freight Transportation by Rail

K. Vaičiūtė¹, A. Katiniene², G. Bureika³

¹Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania, E-mails: kristina.vaiciute@vgtu.lt
²Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania, E-mails: ausra.katiniene@vgtu.lt
³Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania, E-mails: gintautas.bureika@vgtu.lt

Abstract

The processes of technological development and implementation of technologies in road transport have been thoroughly analyzed in terms of technological, economic and managerial aspects, both, by the managers of transport companies (decision-makers), and scientists. Alternatives of technological development of road transport companies are analysed and assessed according to their impact on development of the company’s services, increase of operational efficiency and competitiveness. One of the main components of technological development are information systems and their management in freight transportation by rail. During the structural analysis of technological development, the components of the development process and the factors determining the development of the road transport company are identified. An expert evaluation questionnaire is developed according to the distinguished quality criteria of the impact of the road transport company activity on freight transportation by rail. Having processed the data of the expert survey, the criteria are arranged and the results of the research are presented. Conclusions and suggestions are presented at the end.

KEY WORDS: road transport company, technological development of the company, freight transportation by rail, expert survey, multi-criteria evaluation.

1. Introduction

When providing high-quality transportation services, it is necessary for land transport companies to exchange information, use and properly select the latest technologies, which facilitate technological development. Researchers Sanchis-Pedregosa et al. [1], Harrison et al. [2], M. Akbari [3] and I. Surdu et al. [4], when analyzing supply chain at the global level, emphasize the importance of effective management of logistics and transport information technologies’ development. The authors argue that new technologies have a more effective impact on service delivery as long as the information transmitted by technological development is compatible and interacts within the cooperating companies. Land transport companies lack interoperability with other rail transport companies, i.e., their transport organization processes do not have effective communication channels [5]. The research done by Frmanzah [6] and Hagiu with Altman [7] confirms that the application of advanced technologies in business improves the company’s performance: reduces operating costs, increases and promotes accountability, and reduces the harmful impact on the environment. Road transport companies have to apply technological development, as electronic communications within and between companies are changing so fast that they instantly turn them into products and services and disseminate the results to customers.

The concept of technological development of land transport is evaluated by scientists and experts as a concept to define the renewal of facilities [8, 9]. Laage-Hellman et al. [10] and Stone et al. [11] in their research emphasized the importance of companies’ cooperation in technology development. The activities of land transport companies have demonstrated the need to cooperate with each other and to reduce pollution in the world through technological development. Technological development includes the tools, devices and equipment designated to create and manage the man-made civilized world and the technological environment. New technologies are generally installed in the old and new objects and determine that such updated objects can be used in a new way. Technological development is only a certain type of activity that allows achieving the set goal, for example: to increase the company’s competitiveness. Meanwhile, Chen and Huang [12] state that the concept of technological development is suitable for generalizing knowledge.

Companies need to ensure that partners have proper technological capabilities and supplier satisfaction can help companies gain preferential access to supplier resources. The process of technological development depends on cooperation with different partners. Therefore, the authors of this article define technological development of the land transport company as the application of new technological tools for the implementation and improvement of innovative logistics and transportation processes related to IT and telecommunications.

Bolodurina, Mishurova [13] and Mammela et al. [14] consider that technological development affects the profitability of companies, their economic growth and resource efficiency. Full compatibility of the interconnection technology between road and rail transport systems must be ensured. Technological development requires sharing of the information between road transport companies and rail transport service providers. Information must be provided quickly,
efficiently and securely. Researchers Ugur et al. [15] state that, in road transport companies, the transmission of information by technological means and the effective exchange of information between the transport companies performing the service by different modes of transport, knowledge of the elements of management of new technology, enable the company to obtain certain information.

Schwab and Sala-i-Martin [16] present three major subsystems based on the technological development features of the land transport company for its activity, from which productivity promotion is distinguished (higher education / courses, commodity market efficiency, labour market efficiency, financial market development, technological literacy and market size). Thus, to generalize, the impact of technological development is significant and depends on cooperation and interaction with different partners of land transport companies. The impact of technological development is significant for the quality of transportation performed by land transport companies, and for the company’s performance itself.

During this research, the processes of technological development of the road transport company and the rail transport company are analyzed and evaluated. The authors, using generally accepted methods, seek to assess the impact of the technological development of the land transport company on the efficiency of rail freight transport and the capacity of railway lines.

2. Methodology for Evaluating the Technological Development of Road Transport Companies

The application of innovations and improved technologies in land transport activities is in turn changing the economic situation. Acquisition of new knowledge and training of staff should also include the ability of the parties to innovate and improve technology in the process of acquiring knowledge [17]. Management of this system influences the results of the collaboration. For road transport companies, the possibility of technological development may be acceptable, in case the technological literacy of employees is high. A technologically literate employee of a transport company is able to organize processes: from the simplest design process to the most complex process, and is able to use technological equipment in the business environment, which is a decisive indicator of literacy [18]. Road transport companies must ensure that the cooperating companies have equal technological opportunities, or that the service provider could develop the necessary customer attractiveness, and that the satisfaction of the service providers could help the cooperating companies to gain preferential access to the service providers’ resources / information. According to Kavadias et al. [19] technological development is typically related to changes of a business model, which usually requires significant investment. A would-be business model will reflect a strong interrelated bond between technology opportunities and market needs.

In order to assess the impact of the technological development of the Road Transport Organization, an algorithm consisting of four stages has been developed. The 1st stage is designated for preparation, i.e., a questionnaire is drawn up. In the 2nd stage, the experts are selected according to the time they have been working, and the course of evaluation is introduced to them. In the 3rd stage, the expert survey is conducted, the compatibility of the data matrices and the expert opinions are calculated, which are determined when calculating the concordance coefficient of the Kendall ranks. If the opinions are reconciled, the 4th, data processing stage, is carried out.

Taking into account that the minimum recommended size of an expert group, when forming an expert group, may be 3 experts, it is recommended to include at least 5 experts, in order to increase the reliability of the expert assessment. Meanwhile, many scholars argue that the optimal expert group size is 8 to 10 experts [20, 21]). In order to ensure sufficient representativeness of the survey results, the target segment of the survey has been determined, i.e., 8 experts that meet the following criteria were interviewed: the education of an expert should be in the field of logistics and / or transport management (engineering), he / she should have at least 5 years of work experience in a transport organization and at least 3 years of management experience of at least 10 people’s group. In case of uncertainty, the experts were consulted using online and mobile chat programmes.

Based on the AHP methodology, a ranking method was used to determine the m objects to be quantified by the expert group n. The questionnaire uses questions with programmed answers, giving you the opportunity to choose an answer. The expert group n quantifies m objects. The ranking of expert indicators is suitable for calculating the concordance coefficient. Ranking is a procedure in which the most important indicator is given a “rank R” that equals to one; the second indicator is given a second rank, and the last indicator is given a “rank m” (m is the number of benchmarks). The average of all ranks is calculated.

3. Impact Assessment Results of Companies’ Technological Development on Rail Freight Transport

The study involved 8 experts, all of them having management experience in land transport field, from 3 to 10 years. All the respondents agree that technological development is a means of transmitting or exchanging information to ensure the quality of the road transport services in rail transportation. The study examined the following criteria:

a) new technologies have a more effective impact on the provision of services, if the information transmitted by technological development is compatible and interoperable within the cooperating companies;

b) road transport companies need to apply technological development, for the reason that electronic communications within and between companies are changing so fast that they instantly turn them into products and services, and disseminate the results to customers;

c) technological development is necessary to share the information between road transport enterprises when cooperating with railway service providers; it must be provided quickly and efficiently;
d) in road transport companies, the transmission of information by technological means and the exchange of information between the transport companies that provide the service by the various modes of transport must be efficient;

e) road transport companies must ensure that the cooperating companies have equal opportunities, or that the service provider can develop the necessary customer attractiveness, and that the satisfaction of the service providers can help the cooperating companies to obtain preferential access to the resources / information of the service providers;

f) compatibility of linking technology between road and rail transport systems;

g) technological development of road transport companies is acceptable because the technological literacy of employees is high;

h) impact of the lack of funds on technological development of a road transport company.

In accordance with the above-mentioned criteria (a–h), the impact of technological development of the road transport company was assessed by the experts, giving points from 1 to 8 whereas 1 being the most important, 8 being the least important. The results of the survey are presented in Fig. 1.

![Distribution of the expert-estimated criteria](chart)

Fig. 1 Distribution of the expert-estimated criteria

The responses of eight experts were processed and the findings obtained are listed in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Mathematical expression of the indicator</th>
<th>Criteria encryption symbol ((m = 8))*</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sum_{i=1}^{n} R_{ij})</td>
<td>a  b  c  d  e  f  g  h</td>
</tr>
<tr>
<td></td>
<td>53  52 37 27 19 28 43 29</td>
</tr>
<tr>
<td>(R_j = \frac{1}{n} \sum_{i=1}^{n} R_{ij})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6625 6.5 4.625 3.375 2.375 3.5 5.375 3.625</td>
</tr>
<tr>
<td>(\sum_{i=1}^{n} R_{ij} - \frac{1}{2} n(m+1))</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17 16 1 -9 -17 -8 7 -7</td>
</tr>
<tr>
<td>(\left[ \sum_{i=1}^{n} R_{ij} - \frac{1}{2} n(m+1) \right]^{2})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>289 256 1 81 289 64 49 49</td>
</tr>
</tbody>
</table>

The concordance coefficient has been calculated according to formula (1) when there are no linked ranks:

\[
W = \frac{12 \cdot S}{n^2 (m^3 - m)} = \frac{12 \cdot 1078}{8^2 \cdot (8^3 - 8)} = 0.4010 .
\]  

The impact of technological development is important for road transport companies in the field of rail freight transport, the number \(m > 7\). The weight of the concordance coefficient is then calculated according to formula (2) and a random value is obtained.
\[ \chi^2 = n(m-1)W = \frac{12S}{nm(m+1)} = \frac{12 \cdot 1078}{8 \cdot (8+1)} = 22.4583. \]  \hspace{1cm} (2)

\( \chi^2 \) calculated value was 22.4583; it was higher than the critical value of 14.0671; that is why the opinion of the respondents is considered to be compatible, and the average ranks show the general opinion of the experts:

\[ W_{\min} = \frac{\chi^2_{0.05}}{n(m-1)} = \frac{14.0671}{8 \cdot (8-1)} = 0.2511 < 0.4010. \]  \hspace{1cm} (3)

The minimum value of the concordance coefficient \( W_{\min} \) was calculated according to formula (3), \( W_{\min} = 0.2511 < 0.4010, \) so that the opinions of all the 8 respondents on the 8 technological development criteria that are important for road companies in organizing rail freight are still considered to be compatible.

Significance indicators \( Q_j \), showing the impact of the road transport company’s technological development on the effectiveness of rail freight transport are calculated. The obtained figures are presented in Table 2.

<table>
<thead>
<tr>
<th>Mathematical expression of the indicator</th>
<th>Criteria encryption symbol ((m = 8)*)</th>
<th>Suma</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_j )</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>d_j</td>
<td>0.8160</td>
<td>0.8194</td>
</tr>
<tr>
<td>Q_j</td>
<td>0.1166</td>
<td>0.1171</td>
</tr>
<tr>
<td>Q.j*</td>
<td>0.0660</td>
<td>0.0694</td>
</tr>
</tbody>
</table>

Importance of the criteria of technological development’s influence of road transport companies on rail freight transport, ranking from the most important to the least important criterion, is revealed in Table 2.

Based on expert assessments and calculations, 5 main criteria have been presented:

1. Road transport companies need to ensure that the cooperating enterprises have equal opportunities, or that the service provider can develop the necessary customer attractiveness, and that the satisfaction of the service providers can help the cooperating companies to obtain preferential access to the service providers’ resources/information.
2. Information transmission by technological means in road transport companies and efficient exchange of information between the transport companies that provide the service by different modes of transport; knowledge of the elements of the new technology management.
3. Compatibility of connecting technologies between road and rail transport systems.
4. Non-allocation of funds affects the technological development of the road transport company.
5. The necessity for technological development for rapid sharing of information between road transport companies when cooperating with railway service providers.

The experts have revealed in which areas technological development is necessary in the current operation of the company. The survey has also revealed that the majority of respondents (90.3%) believe that technological development should be of a major concern in the future. The computer literacy of the employees of the road transport company must be constantly developed in order to know the elements of the new management technology. The development of technological competencies is of particular importance: the ability to take advantage of new IT opportunities to develop collaboration and to accelerate information management.

### 4. Conclusions

1. The results gained by investigation have proved that the application of advanced technologies in the transport business significantly improves the company’s economic performance, and technological development accelerates the transmission of information, and ensures the quality of road transport company’s services in rail transport.
2. It was has revealed that a strong focus should be placed on technological development, and the computer literacy of the road transport company’s workers, as well as their knowledge of the elements of new technology management, have an impact on rail freight.
3. In order to ensure the competitiveness of the road transport company, the management staff (decision makers) must intensify the technological development of the company and improve the ability of the employees to use the opportunities provided by new IT.
4. During the research, the experts identified 5 main criteria of enterprise technological development. These are equal technological opportunities for cooperating companies; transmission of information by technological means and efficient exchange of information; compatibility of connecting technologies between road and rail transport systems; non-
allocation of funds for technological development; the inevitability of technological development for fast and efficient sharing of information between road transport companies when cooperating with railway service providers.

Reference

Development Prospects of the Ukrainian Section of the Shipping Route E-40

I. Gladkykh¹, A. Golikov², I. Vorokhobin³, M. Kulakov⁴

¹National University «Odessa Maritime Academy», Didrihsiona 8, 65000, Odessa, Ukraine, E-mail: gladkykh958@gmail.com
²National University «Odessa Maritime Academy», Didrihsiona 8, 65000, Odessa, Ukraine, E-mail: agolikoff@gmail.com
³National University «Odessa Maritime Academy», Didrihsiona 8, 65000, Odessa, Ukraine, E-mail: vorokhobini@gmail.com
⁴National University «Odessa Maritime Academy», Didrihsiona 8, 65000, Odessa, Ukraine, E-mail: endeavorlxze1@gmail.com

Abstract

The shipping route E-40, which is considered in the EU, as one of the priority areas for the development of transport networks in Europe. The project involves connecting large European waterways between the three seas, the North, Black and Baltic. One of the largest sections of this route is located on the territory of Ukraine; therefore, this article discusses issues related to the prospects of its development from the point of view of modernity. The main task of modern shipping is its safety and effectiveness.

KEY WORDS: transport networks, safety

1. Introduction

The history of our development shows that almost all the human imagination, associated with its activities, will find their practical application sooner or later. In such a way the idea of the shortest route from the Varangians to the Greeks nowadays is reflected at the implementation of the E40 shipping route project. Hereunder is a brief overview of the current status of work carried out under this project.

The International Waterway (IWW) E-40 connects the Baltic Sea with the Black Sea. It begins in Gdansk, then on the Polish section runs along the Vistula River and the Western Bug to Terespol and further to the Polish-Belarusian border. In Belarus, the waterway runs along the Mukhavets River, the Dnieper-Bug Canal, the Pina and Pripyat rivers to the Belarusian-Ukrainian border.

In Ukraine, the E-40 waterway is formed by the Pripyat and Dnieper rivers, which lead to Kherson and the Black Sea. The total length of the waterway is more than 2000 kilometers.

The main obstacle to navigation along this route is the section between Warsaw and Brest, which is not navigable currently. Research conducted as part of the project “The E40 main waterway restoring on the Dnieper-Vistula stretch: from strategy to planning” showed that to eliminate this obstacle, it will require the construction of a new canal in Poland from Warsaw to Brest, as well as a number of construction and reconstruction hydraulic works on the Belarusian, Polish and Ukrainian territories with the aim of improving navigability along the entire length of the E-40 waterway.

2. Research

The international waterway E-40 crosses 14 regions. It can combine not only the Baltic Sea with the Black Sea, but also the Black Sea and the North, so that internal transport by IWW could unite almost all European countries. A diagram of this path is shown in Fig. 1.

Let’s consider what will be with economic effectiveness in case of realization of the project in the near future [1]. Transportation of goods by E-40 waterway will take more than 14 days. It is longer than by road or rail. However, in case of long distance and heavy cargo, the water transport becomes more profitable, because on this route one barge can replace 40 trucks adapted for transporting containers. The advantage of inland water transport becomes noticeable for the transportation of goods for distance over 500 km, as given in Table 1.

<table>
<thead>
<tr>
<th>№</th>
<th>Type of transport</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Railway transport</td>
<td>more than 82 000 euros</td>
</tr>
<tr>
<td>2</td>
<td>Road transport</td>
<td>more than 78 000 euros</td>
</tr>
<tr>
<td>3</td>
<td>Water transport</td>
<td>56 000 – 57 000 euros</td>
</tr>
</tbody>
</table>
Proposed level of fees for using the waterway:
- 5.9 for one lockage of cargo vessel on the Vistula-Mukhavets canal;
- rate for using the canal: 0.024-0.026 per 1 km of a forty-foot container.

The proposed tariffs are lower than on the waterways of Western Europe, but allow you to achieve profit on the selected route option, which will be higher than the annual operating costs of the waterway according to the "user pays" principle.

Fig. 1 Scheme of the International E40 Waterway

The calculation of the navigation parameters of the canal are as following [2]:
1. Depth of the shipping canal.

The minimum canal depth \( h_k \) is calculated by adding the draft of the watercraft \( T \) and the safety margin between the bottom of the watercraft and the bottom of the waterway \( \Delta t \):

\[
h_k = T + \Delta t \quad [m],
\]

where \( T = 2.50 \text{ m} \) – draft of the watercraft; \( \Delta t = 1.0 \div 1.5 \text{ m} \) – depth reserve for bottom protection from the negative impact of the watercraft propellers, adopted \( \Delta t = 1.5 \text{ m} \).

\[ h_k = 2.50 + 1.50 = 4.0 \text{ m}. \]

2. The width of the navigable canal.

Great importance has dimensions during designing the canal cross-sectional shape, such as: minimum depth \( h \), reliable width \( b \), usable width \( b' \), as indicated in Fig. 2.

Useful waterway width refers to the width, at which the minimum depth \( (h) \) will be provided at each location. The valid width \( (b) \) is the width at the bottom of the fully loaded barges. For straight sections of a bidirectional canal, the reliable width is determined by the formula:

\[
b = 2 \cdot B_s + 3 \cdot \Delta B_s ,
\]

where \( B_s = 11.4 \text{ m} \) – the width of the watercraft; \( \Delta B_s \) – distance between vessels and between the vessel and the shore (at the vessel level).

Fig. 2 Trapezoidal cross section of the navigable canal
The safe value $\Delta B_s$ depends on the type of craft. It is accepted that for international waterways of class IV or higher it should not be less than 5 m.

$$b = 2 \cdot 11.4 \, \text{m} + 3 \cdot 5 \, \text{m} = 37.8 \, \text{m}.$$  

3. Indicator of navigability.
Indicator of navigability ($n$) is determined by the formula:

$$n = \frac{F}{f} \geq 7,$$  

where $F$ – the cross-sectional area of the canal; $f$ – the cross-sectional area of the submerged part of the watercraft.

Calculations by the example of one of the narrow sections of the Dnieper River:

$$F = \frac{b_2 + b_1}{2} \cdot h_b;$$  

$$F = \frac{(37.80 + 2 \cdot 2 \cdot 2.50) + (37.80 - 2 \cdot 2 \cdot 1.50)}{2} \cdot 4 = 159.2 \, \text{m}^2;$$  

$$f = B_1 \cdot T;$$  

$$f = 11.4 \cdot 2.5 = 28.5 \, \text{m}^2;$$  

$$n = \frac{159.2}{28.5} = 5.58 < 7 \rightarrow \text{the condition is not satisfied}.$$  

Assume that the section has been expanded to a minimum value for the class $V_{a}$ waterway – 45 m.

$$F = \frac{b_2 + b_2}{2} \cdot h_b = \frac{(45.0 + 2 \cdot 2 \cdot 2.50) + (45.0 + 2 \cdot 2 \cdot 1.50)}{2} \cdot 4 = 188.0 \, \text{m}^2;$$  

$$n = \frac{188.0}{28.5} = 6.59 < 7 \rightarrow \text{the condition is not satisfied yet}.$$  

Due to the fact that the condition is not satisfied yet, the width of the site must be increased to 50 m.

$$F = \frac{b_2 + b_2}{2} \cdot h_b = \frac{(50.0 + 2 \cdot 2 \cdot 2.50) + (50 + 2 \cdot 2 \cdot 1.50)}{2} \cdot 4 = 208.0 \, \text{m}^2;$$  

$$n = \frac{208.0}{28.5} = 7.30 < 7 \rightarrow \text{the condition is satisfied}.$$  

Finally, it can be accepted that the width of the waterway in the selected section should be equal to 50 m.

4. Waterway arc radius.
The cross-section in the bends will be slightly different due to the rigid compositions on the arcs describe their extremities arc radii, the difference of which is greater than own width of the composition, when the radius of curvature is smaller and the length of the composition is longer, inter alia depending on the speed.

$$R_{\min} = 5 \cdot L;$$  

where $R_{\min}$ – the smallest arc radius of the navigable canal of a path class $V_{a}$, adopted $R_{\min} = 650 \, \text{m}$.

The broadening on the arcs is calculated by the formula:

$$B = \frac{L^2}{2R},$$  

where $R$ – radius of the arc; $L$ – length of the watercraft.
Assuming the minimum value of the arc radius axis of the shipping route $R = 650$ m for the class, and the length of the target fleet, i.e. pushed composition 115 m, the minimum broadening on the arc will take on the value:

$$B^* = \frac{L^2}{2R} = \frac{115^2}{2 \cdot 650} = 10.17 \text{ m}.$$ 

The smallest bidirectional canal width is:

$$b_3 = B + b_1,$$

$$b_3 = 50 + 10.17 \text{ m} = 60.17 \text{ m} \rightarrow \text{accepted 62 m}.$$ 

Determination of the operational capacity of the waterway by the formula:

$$P_e = P_i \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \left( \frac{\text{million tons}}{\text{year}} \right),$$

where $\alpha_1$ – an indicator of uneven movement due to different ship speeds, $\alpha_1 = 0.6 \div 0.8$, accepted $\alpha_1 = 0.7$; $\alpha_2$ – an indicator of uneven port operation, $\alpha_2 = 0.7 \div 0.9$; accepted $\alpha_2 = 0.8$; $\alpha_3$ – an indicator of cargo capacity limitation, $\alpha_3 = 0.75$; $\alpha_4$ – an indicator of the impact of two-way traffic, $\alpha_4 = 0.90$.

$$P_e = 75.16 \cdot 0.7 \cdot 0.8 \cdot 0.75 \cdot 0.9 = 28.41 \text{ million tons per year}.$$ 

Fig. 3 The main ports on the Ukrainian section of E40

Brief overview of the E40 waterway was given above, where demonstrated the main characteristics for shipping and also the viability of this project. Below we would like to dwell on those issues that are unifying common standards and striving to their further development in the EU countries and in neighboring countries. The questions are closely related to the development and implementation of River Information Services (RIS). Hereafter is a brief overview of RIS and what tasks facing Ukraine to harmonize UKRRIS in the European system in combination with the E40 project in the "Dnieper Transport Development" within the framework of the European project. Together with representatives of the project we conducted a compatibility analysis of the Ukrainian RIS system with the European one. The main ports on the Ukrainian section of E40 are given on the Fig. 3.

In Inland Waterway Transport the concept of River Information Services was introduced in the early 90's of the previous century. In the meantime, this concept is world-wide under implementation. The concept of RIS was also adopted in Ukraine and has resulted in information services on the Danube and Dnieper rivers presented by UkrRIS. In the Assistance Program for the Dnieper Transport Development the status of RIS on the Dnieper will be assessed and proposals will be depicted to enhance and extend River Information Services on the basis of the needs and requirements of IWT on the Dnieper.

UkrRIS can be enhanced on short term with little effort to a more advanced and compliant River Information Services and consequently will provide:

- lock management information services for lock operators;
- port and terminal traffic information services for port and terminal operators;
RIS services for emergency response organizations;
though combining Inland AIS and Inland ECDIS in information mode more effective safety services are provided on board of vessels.
The precondition is that basic key technologies are made compliant with the Commission Regulations and basic reference data will be adopted like there are in special the RIS Index and the European Number of Identification (ENI) vessel code.

Consortium Operational Management Platform River Information Services (COMPRIS) was also the basis for the European Commission to formalize in 2005 River Information Services in the RIS directive.

Important achievements of the research period on River Information Services were:
- the development of a framework for European co-operation on the implementation of RIS and the RIS technical standards;
- the development of more user-oriented applications not only for Vessel Traffic Management (VTM) and safety of navigation but oriented also to value-added service to the transport industry;
- AIS transponders according to the IMO standards can be applied in inland navigation, thus contributing to safe navigation. They are particularly useful if areas of mixed traffic of maritime and inland navigation, areas with high shipping densities and areas with special navigational difficulties.
- inland ECDIS turned out to be a very strong platform for a number of tactical and strategic applications;
- intelligent coding of Notices to Skippers (NtS) brought national oriented NtS to a European level, independent of the languages in the European members states, Russia and Serbia;
- electronic Reporting proved to be successful in avoiding confusing communication on transport data especially for dangerous goods transport.

The Dnieper river is part of the important section of the E40 waterway, and the part downstream of Kyiv, the Dnieper is a class Vb waterway. The transport sector is important in Ukraine's economy and efficiency improvements are particularly important for increasing competitiveness. Information and communication technologies and more recent digitalization is transforming our economy and society at a rapid pace. This is a worldwide development, in which Information and Communications Technology (ICT) and Digital Technologies are used in all transport modes as an important source of growth, innovation and new business.

3. Conclusions

Based on the above, we can draw the following conclusions:
- the shipping route E40 is an important component of the development of economic relations of European countries;
- the creation of a single information space, using common standards, allows us to solve a number of very important tasks in the field of shipping on IWW. This is ensuring environmental and navigation safety, logistics, processing of electronic documents of a single sample, etc.;
- in general, UkrRIS is sufficiently deployed and equipped in order to solve the tasks assigned to it, however, for successful work in the common European system it is necessary to provide the following:
  1) perform RIS indexing of all objects (navigation signs, port facilities, gateways, etc.) displayed on the navigation map. It will combine all the RIS standards in a single information field;
  2) bring the entire set of hardware and software to modern requirements in accordance with the recommendations of the EC and the RIS manual;
  3) provide reliable communication canals for exchanging information with other European RIS centers;
  4) establish contractual relations with parties, both public and private, interested in obtaining RIS information, as well as determine the limits of access restrictions to the amount of information they receive;
  5) develop a training course for advanced training for the operator's RIS;
  6) modernize the system of location of aids to navigation on the Dnieper using AIS and Virtual buoys.

References

The Use of Passenger Cars in Business in the Czech Republic in the Context of Developments and Trends in Financing and Accounting and Tax Aspects

J. Hakalová¹, A. Bieliková², Š. Kryšková³, Y. Pšenková⁴, M. Palochová⁵

¹VŠB - Technical University of Ostrava, Faculty of Economics, Department of Accounting and Taxes, Czech Republic, E-mail: jana.hakalova@vsb.cz
²VŠB - Technical University of Ostrava, Faculty of Economics, Department of Accounting and Taxes, Czech Republic, E-mail: alezbeta.bielikova@vsb.cz
³VŠB - Technical University of Ostrava, Faculty of Economics, Department of Accounting and Taxes, Czech Republic, E-mail: sarka.kryskova@vsb.cz
⁴VŠB - Technical University of Ostrava, Faculty of Economics, Department of Accounting and Taxes, Czech Republic, E-mail: yvetta.psenkova@vsb.cz
⁵VŠB - Technical University of Ostrava, Faculty of Economics, Department of Accounting and Taxes, Czech Republic, E-mail: marcela.palochova@vsb.cz

Abstract

This paper deals with the analysis of using passenger cars in the business of individuals and legal persons in the Czech Republic, with a focus on selected issues of accounting and tax aspects. The use of passenger cars is, of course, essential for doing business today, and in the context of rapidly evolving trends and developments in the automotive industry, with the fast-growing current trend of electrification and electromobility, and especially the growing profits of business entities, we can see not only changes in financing, but also in the approach of business entities when choosing a brand or type of passenger cars. The paper focuses on the analysis of the situation with the use of passenger cars in business from the perspective of possible sources of financing and developments in this area, adjusting the values of permanent and transitional character in its use, tax aspects from the perspective of direct and indirect taxes as well as monitoring usage trends in the Czech Republic and worldwide.

KEY WORDS: car, accounting, taxes, value adjustments, financing, development, trends.

1. Introduction

For the performance of business activities in the Czech Republic, the use of cars is an almost necessary part of every business practice. A car provides entrepreneurs with the mobility and independence needed to make business trips as well as the costs by which entrepreneurs can reduce their business tax base. The number of registered passenger cars in the vehicle register in the Czech Republic has been growing in recent years, and the number of funds collected from the collection of road tax, which in the Czech Republic is paid only for vehicles used for business, according to statistics published by the General Financial Directorate amounted in 2015, for example, 5,814 billion CZK, in 2016 it was 5,970 billion CZK, in 2017 it was 6,191 billion CZK and in 2018 it was more than 6,276 billion CZK [14].

![Fig. 1 Ways of purchasing a passenger car in the Czech Republic](image_url)

The use of a car in the business of individuals or legal persons, however, brings a number of questions and ambiguities in terms of accounting and taxation. The most common decision when starting a business made by entrepreneurs-individuals is whether or not to include their own vehicle into a business asset or what the most suitable form of its financing may be. Whether to buy a car for business purposes in cash, that is from a supplier, on credit, or through financial or operational leasing, as a gift or by including in business asset etc. In recent years, operational leasing has become more significant in the Czech Republic due to changes in tax laws. In the case of legal entities, this includes also a decision on how the car will be used by employees, whether it will be available to the employee at all times and one percent of the car's purchase price will be added to the gross wage, or the car will be used in another way. All of these options bring entrepreneurs, as well as their employees, advantages and disadvantages, both from the
accounting and tax point of view [2]. The category of vehicle for business purposes is usually chosen by the entrepreneur in accordance with the type and scope of the business. The most frequently used car in business, with the exception of road transport, is currently a passenger car. The most common ways of acquiring a car in the business environment are shown in Schema 1.

2. Analysis of Ways of Purchasing a Car and Their Impacts

Passenger cars, which are used by individuals and legal persons for their business activities, can currently be acquired in various ways, as already mentioned in the introduction to this paper. Each of the selected acquisition methods has an impact on its recognition in accounting and is then reflected in the value of reported assets in the financial statements. One of the most common ways to acquire a car is to buy one. Another, less common way for entities to purchase a car is to obtain it as a gift; they can purchase it on their own, i.e. to produce it internally or include it into their business asset. Entrepreneurs-individuals who own their own private car do not have to include this vehicle in their business asset. The passenger car will not be registered by the entrepreneur in the accounting, and since the car is not included in the entrepreneur's business assets, the entrepreneur cannot depreciate it but will claim basic compensation per kilometre driven and reimbursement for fuel consumption [4]. Among the advantages of this way of using a passenger car is the fact that the entrepreneur does not have to spend money or does not have to get into debt in order to use a passenger car for own business activities. In case of lack of free funds, a car can also be purchased on credit. In most cases, it will be a special-purpose loan tied to the purchase of a specific item. Although the asset is acquired from external sources of financing, the entrepreneur has the right to depreciate it for tax purposes at the time of its purchase, which does not apply to leasing, for example. Interest arising from a loan are a tax-deductible expense. The disadvantage of buying on credit is the need to incur additional costs associated with the loan. A lease is another way to purchase a car if the entrepreneur does not have enough free funds. The entrepreneur can use financial or operational leasing when renting. In the case of financial leasing, ownership passes from the lessor to the lessee at the end of the contract. The duration of this type of leasing contract usually coincides with economic life of the asset and is therefore longer-term. Passenger cars are depreciated according to the Act on Income Tax for 5 years, and a financial leasing is therefore set for this minimum leasing term. Ownership risks and obligations associated with maintenance and repairs of financial leasing are on the side of the lessee. On the other hand, in the case of an operational leasing, the asset remains the property of the lessor even after the end of the leasing contract. Generally speaking, an operational leasing is understood as all other types of leasing contracts that are not financial leasing. The leasing term is usually shorter than for financial leasing and also shorter than economic life of the property. The lessor usually pays the costs associated with the maintenance, repair and servicing of the leased property. If the entity complies with the accounting procedures and conditions specified in the Act on Income Tax, the lease is in principle always a tax-deductible expense [1]. There are various accounting and tax connections that arise with the acquisition, use and also with the exclusion of cars from business asset which one needs to know in business practice. Acquisition of a car by purchase can be realized in the form of a purchase for cash or with an invoice, loan or a leasing contract. Of course, each of these acquisition methods also has an impact on the cash flow of every accounting entity. Businesses do not prefer the purchase of a car for cash or with an invoice, for the obvious reason which is the immediate withdrawal of funds that has a negative effect on the cash flow of the entity as there is a one-time reduction in available funds. If such method of purchasing a passenger car is applied, its acquisition price is included into business assets of the accounting entity. In the method mentioned above, a one-time reduction in available resources is the reason why accounting entities prefer to buy a car in the form of a loan or leasing contract. The form of financing a passenger car on credit is interesting for accounting entities, given that the passenger car is immediately in their ownership and therefore is a part of the reported fixed assets and is subject to depreciation. Furthermore, the regular repayment of the loan burdens the cash flow of the accounting entity on an ongoing basis. Tax depreciation is a tax-deductible expense that affects the amount of the tax base. In the same way, interest on a loan is a tax-deductible expense if the passenger car is used only and exclusively for business purposes. If a private car is used also for private purposes, the amount of interest applied is reduced by a proportional part. The loan repayment itself is then no longer tax effective. The fact that accounting entities quite often use various subsidy programs, through which investments in new tangible assets are supported, is also important for the purchase of a passenger car on credit. However, their allocation is often tied to the ownership of the thing by the accounting entity. When financing with a loan, the accounting entity is always burdened by more complicated handling of all formalities and also by checking own solvency. In the case of leasing, business entities have two options, namely acquisition in the form of operational or financial leasing. In both types of leasing, the leasing company is the owner of the car for the period of payment of lease payments. The difference between them occurs only upon completion of repayment, when in the case of financial leasing the ownership right is transferred to the lessee. In the case of an operational leasing (a lease), the subject of the leasing remains the property of the lessor even after the end of the leasing contract. Operational leasing (a lease) is offered in the form of both short-term and long-term leasing. In addition to the depreciation of a passenger car, other items such as compulsory car insurance, accident insurance, road tax or vignette are usually included in a payment of an operational leasing. Its advantage is that the lessee has minimal administrative burden for operational leasing, most of the necessary formalities will be arranged for them by the leasing company. The same applies to financial leasing. In the case of financial leasing, the lessee obtains the subject of the leasing contract after the termination of the contract for the repurchase value which is agreed in the contract, and the passenger car will be then included in the business asset at the amount of the acquisition price [7]. The purchase price
can also be zero when it is a free-of-charge acquisition of an item after the end of the financial leasing, the subject will be valued at the reproduction cost and subsequently included in the business assets as tangible fixed assets or small tangible fixed assets. According to the report on the state and development of the non-bank leasing, credit and factoring market in the Czech Republic in 2019, which was issued by CLFA (Czech Leasing and Finance Association), in terms of commodity focus, the share of leasing contracts for passenger cars was 37.9% and the share of leasing contracts for trucks (lorries) was 25.1%, another share concerned the leasing of machinery and equipment. Of the total number of new contracts for leasing of machinery, equipment and means of transport for entrepreneurs, there was a year-on-year decrease of 2,796 contracts which is a decrease of 5.3% compared to last year. Most households prefer a consumer loan when financing a new car. According to statistics from the Czech Leasing and Finance Association (CLFA), 90% of households did so last year, see Figure 1. The situation is different in the corporate sphere. Measured by the number of concluded contracts, last year 51% of business entities preferred operational leasing when financing a new passenger car, i.e. car lease supplemented by services related to its operation. In contrast, 49% of corporate clients preferred the traditional method of financing, i.e. a special-purpose business loan or a similarly conceived financial leasing, see Figure 2. In the business sphere, operational leasing predominates more than by a half. Last year, CLFA member companies financed almost 30% of all newly registered passenger cars in the Czech Republic. Specifically, there were 73,029 vehicles, three quarters of which were intended for companies and one quarter for consumers (households). In total, the members of the association provided 34.35 billion CZK for new passenger cars which is 0.9% less year-on-year than last year. Companies used 87% of this amount, and 13% went to households [13].

![Fig. 1 Proportion of products intended for financing new passenger cars for households in 2019 by the number of newly concluded contracts of CLFA's members](image1.png)

![Fig. 2 Proportion of products intended for financing passenger cars for companies in 2019 by the number of newly concluded contracts of CLFA's members](image2.png)

The use of passenger cars for business of individuals and legal persons in the Czech Republic is associated with a number of costs, whether they occur daily, monthly or annually. These costs include tolls for the use of expressways and motorways in the form of a one-time payment. In the Czech Republic, they are divided into vignettes (for passenger cars) and electronic tolls (for trucks/lorries). For 2020, the value of the annual coupon is 1,500 CZK, the monthly coupon is worth 440 CZK and the ten-day coupon is 310 CZK. The road tax is another cost [9] the height of which depends on the engine displacement in cm³ for passenger cars [9]. For engine displacement up to 800 cm³, for example, the tax rate is 1,200 CZK and for engine displacement over 3,000 cm³, the tax rate is 4,200 CZK. When operating a car for business, it is also necessary to take into account the normal daily cost, which is fuel consumption. These can be accounted for in the amount of actual costs according to the receipts from the purchase of fuels, or it is possible to use the average price of the fuels [10] which for 2020 are given by a Decree [11], which for the first time for 2020 states the rate for 1 kilowatt hour of electricity in case of using electric cars. This is about an ever-increasing number of electric cars and plug-in hybrids, an increase of 25% year-on-year compared to the previous year. Of this number, 756 were electric cars and 473 plug-in hybrids [12]. Chapter 4 deals with the mentioned emerging trend of electric cars.

3. Problem Areas Related to Accounting and Tax Aspects

**Adjusting values of permanent character**

With regard to the purchase price and useful life, passenger cars are classified as fixed assets. The total expenses incurred for the acquisition of a passenger car cannot be reflected in the costs as a one-off as these are assets with a useful life of more than one year. During the useful life of a passenger car, its value gradually decreases in connection with its physical and moral obsolescence (e.g. due to newer technologies used in its production). The passenger car is therefore worn out gradually and this permanent decrease in its value is expressed in the form of depreciation which according to Czech accounting legislation is debited to operating expenses (account group 55) and credited to the relevant accumulated depreciation account (account group 08). Accumulated depreciation represents the accumulated amount of depreciation of a passenger car for the entire period of its use. In the Czech Republic, a permanent decrease in the value of assets is reported in the balance sheet under the item of adjustment to assets and in the profit and loss statement as an expense, which is shown in Tables 1 and 2. In the Czech Republic, the distinction between accounting depreciation and tax depreciation is very important for depreciation. Accounting depreciation is regulated by the Act on Accounting and the relevant implementing regulation to this Act [8]. Tax depreciation is regulated by the Act on
Income Tax.

The method of determining the amount of accounting depreciation is in the competence of each accounting entity and must be regulated by an internal directive – a depreciation plan. The passenger car is therefore depreciated on the basis of a depreciation plan indirectly through accumulated depreciation. The methodology for determining accounting depreciation is determined by the accounting entity itself in accordance with the provisions of the Accounting Act (Section 28 (6)) and the implementing regulation (Section 38). Accounting depreciation is calculated from the price at which the passenger car is valued in the accounts (up to its maximum amount) and should express the actual degree of wear and tear of the property. Accounting depreciation should result in a fair recognition of the value of the property and spread the cost of the passenger car over its useful life. The methodology of accounting depreciation of a passenger car is chosen by the accounting entity itself. The entity can use the following methods:

- time-based methods (straight-line accounting depreciation, degressive and progressive accounting depreciation);
- performance-based methods;
- component depreciation methods.

The time depreciation methods are based on the useful life of a passenger car, and accounting theory distinguishes between straight-line, degressive or progressive depreciation. One of the most used methods of depreciation of a car is linear or straight-line accounting depreciation. The amount of monthly depreciation is determined as the ratio of the purchase price of a car to the number of months of its life.

\[
\text{monthly (straight-line) depreciation} = \frac{\text{acquisition price}}{\text{lifetime in months}}.
\]

When using the degressive or accelerated depreciation method, accounting depreciation is reduced over the life of the car, i.e. in the following year the depreciation must be less than in the year preceding it. The double declining balance method (DDB) or the sum of the years digits (SYD) method can be used to calculate the accelerated depreciation. Progressive or decelerated accounting depreciation increases during the depreciation period. Again, the SYD method can be used here. Degressive or progressive depreciation methods are not very suitable for depreciation of a car as they do not express the actual degree of wear during its lifetime. Both methods are listed here for information only. When calculating the permanent reduction in the value of a passenger car, the most appropriate method seems to be the method of performance which is based on a certain capacity of the asset. In the case of a passenger car, the capacity means the maximum number of kilometres travelled during its lifetime. The performance method is strongly focused on the physical wear and tear of the car, and its great advantage is that in comparison with the time methods it can best express this physical wear and tear. When calculating the amount of depreciation, it is important to calculate the depreciation rate which expresses the reduction in the value of the car by driving one kilometre.

\[
\text{depreciation rate} = \frac{\text{acquisition price}}{\text{expected performance of the asset}},
\]

monthly depreciation = depreciation rate \( \times \) output in the \( i \)-th month.

Component depreciation of tangible assets is another option that can be used in accounting, but it is hardly used for depreciating a car. This is due to the fact that a passenger car is not expected that any of its part is a significant part of the purchase price and at the same time has a shorter useful life than the car as a whole.

Tax depreciation represents the part of the acquisition cost of a passenger car that the entity can claim as a tax-deductible expense for the relevant tax period. Tax depreciation is regulated in Sections 30 to 32a of Act No. 586/1992 Sb., on Income Tax. For the purposes of calculating tax depreciation, a distinction is made between intangible and tangible assets, and the amount of the input price is assessed. For tangible assets, the marginal price is an amount higher than 40,000 CZK; the useful life is always longer than one year. After the car is put into use, the entity classifies it into one of the six depreciation groups listed in Appendix No. 1 to the Act on Income Tax. Passenger cars are included in depreciation group 2 with a depreciation period of five years. A car can be depreciated for tax purposes even longer (i.e. the entire depreciation will not be applied in the given year) or the tax depreciation may not be applied at all. Depreciation can be interrupted and resumed in such a way as if it has not been interrupted. Only half of the annual depreciation can be applied if the passenger car is in the accounting entity's records only at the beginning of the relevant period (i.e. when it is sold, for example, during the year). Tax depreciation is determined off-balance sheet only for the purposes of determining the tax base and does not always accurately reflect the actual wear of the property. It is in fact the maximum amount of depreciation that can be considered a tax-deductible expense. After classifying a passenger car in the relevant depreciation group, the accounting entity decides on the method of tax depreciation. The entity can choose the method of straight-line or accelerated depreciation [6]. The chosen depreciation method may not change during the life of the asset. In the case of straight-line depreciation of tangible assets, the maximum annual depreciation rates are assigned to the depreciation groups.

\[
\text{straight-line (annual) depreciation} = \frac{\text{entry price} \times \text{annual depreciation rate}}{100}.
\]
In the case of accelerated depreciation of tangible assets, depreciation groups are assigned coefficients for accelerated depreciation. When calculating accelerated depreciation, the procedure in the first year is different from the calculation in subsequent years.

\[
\text{accelerated depreciation in the 1st year} = \frac{\text{entry price}}{\text{coefficient in the 1st year of depreciation}}; \quad (4)
\]

\[
\text{accelerated depreciation in subsequent years} = \frac{2 \times \text{residual value}}{\text{coefficient for the next period} - \text{the number of years for which the asset has already been depreciated}}. \quad (5)
\]

At the end of the accounting period, it is necessary, due to the different amount of accounting and tax depreciation, to adjust the accounting result (profit/loss) to the tax base. If the accounting depreciation of a car is greater than the tax depreciation, the income tax base is increased by the difference. If the accounting depreciation is lower than the tax depreciation, the income tax base is reduced by this difference.

**Adjusting values of transitional character**

During the use of a passenger car in business, there are many facts that result in a change in its value. In the accounting of business entities, the decrease in the residual value of a car is mainly influenced by the recognized accounting depreciation or even adjustments. Adjustments in accounting respect one of the important accounting principles, namely the precautionary principle, with which we express in the accounting of commercial corporations possible future risks and losses related to assets and liabilities. Adjustments so eliminate possible overvaluation of assets and undervaluation of liabilities. Adjustments to temporary values are not as common for means of transport as for other tangible fixed assets. Temporary decrease in the value of assets may be caused by temporary non-use of a passenger car, for example, due to sudden damage and future repairs, non-use in case of attenuation of the production process and related non-use according to previous planned usefulness, etc. According to Czech legislation, this decrease is recorded to operating expenses (accounting group 55) which, however, from a tax point of view, do not reduce the tax base of individuals or legal persons doing business but can significantly reduce the profit after tax, the so-called disposable profit. For this reason, commercial corporations often misbehave in this accounting matter and do not report these facts correctly according to the accounting principle of a true and fair presentation of all facts in their accounting, and this incorrect procedure is then negatively commented by the auditors in the auditor's reports during the verification of the financial statements and annual reports of such corporations [3]. From the point of view of recognition in assets, it is a correction of assets and account group 09 is used for such recognition.

From the perspective of the national financial reporting regulations in the Czech Republic, the temporary decrease in the value of assets is reported in the balance sheet in the item of adjustments to assets and in the profit and loss statement as an expense, which is shown in Tables 1 and 2.

### Table 1

**Recognition of a permanent and temporary impairments of assets in the balance sheet in full in accordance with Czech legislation**

<table>
<thead>
<tr>
<th>Designation</th>
<th>ASSETS</th>
<th>Line number</th>
<th>Current accounting period</th>
<th>Prior accounting period</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
<td>c</td>
<td>Gross</td>
<td>Adjustment</td>
</tr>
<tr>
<td>B.II.</td>
<td>2.</td>
<td>Tangible movable things and their groups</td>
<td>18</td>
<td>Reported in accordance with the account balance in account group 02.</td>
</tr>
</tbody>
</table>

**Source:** Notes No. 1, Decree No. 500/2002 Sb.

### Table 2

**Recognition of permanent and temporary impairment of assets in the income statement in accordance with Czech legislation**

<table>
<thead>
<tr>
<th>Designation</th>
<th>TEXT</th>
<th>Line number</th>
<th>Reported in the accounting period</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td>b</td>
<td>current</td>
</tr>
<tr>
<td>E.</td>
<td>Adjustments relating to operating activities</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>E.1.</td>
<td>Adjustments to the value of intangible and tangible fixed assets</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>1.1.</td>
<td>Adjustments to the value of intangible and tangible fixed assets - permanent</td>
<td>16</td>
<td>Reported in accordance with the balance on the relevant account in account group 55.</td>
</tr>
<tr>
<td>1.2.</td>
<td>Adjustments to the value of intangible and tangible fixed assets - temporary</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Notes No. 1, Decree No. 500/2002 Sb.
4. Modern Trends in the use of Cars in the World

Electromobility is a clear trend for the future in the world [15]. We are currently experiencing growing trends in sales in this category of cars. The development of electromobility in the Czech Republic is still at the beginning. The main reasons include the price of an electric car which is higher compared to cars with conventional engines (in the future there is a presumption of lowering the price of batteries and therefore also of electric cars). Furthermore, the absence of a regulatory framework ( electromobility as a form of clean transport has not yet been the subject of support in the Czech Republic, with the exception of excise duty; there is no strategy for its development). Economic reasons ( electromobility is not yet fully commercial, the market is still in the making). Limited offer of vehicles (limited offer of models of various segments in mass sales is related to the fact that the Czech market is not so attractive for major players, and a delay can be expected compared to Western Europe). Absence of charging infrastructure (low density of the charging network, especially in the area of fast charging). Prejudices and mistrust of users, limited practical experience (great weight for the risks associated with electric propulsion, distrust of untested technologies). Low sensitivity to environmental issues, especially reducing CO2 emissions [5]. For these reasons in particular, sales of electric vehicles have been growing slowly so far, although a significant upward trend has been evident in recent years [18]. The great interest in electric cars among the public is confirmed by the latest research by Ipsos which took place in the Czech Republic and Slovakia from April to May 2017. The Ipsos survey shows that about half of the respondents in the Czech Republic declare their interest in buying an electric car within two to three years, with almost 10 percent of them already considering buying it. According to in-depth interviews conducted by Ipsos with fleet managers, it is clear that if they had the option of purchasing on favourable terms, buying a green car would be very realistic to consider [16].

According to an analysis performed by LeasePlan, the Czech Republic is one of the European countries that is least prepared for the advent of electromobility. The Netherlands, Norway and the United Kingdom, on the contrary, are the furthest in this respect. The EV Readiness Index, regularly published by LeasePlan, is an analysis that monitors four factors: market share of electric vehicles (including plug-in hybrids), sophistication of charging station infrastructure, level of state support for electric mobility and representation of electric vehicles in the company's client fleets. In the European comparison, we lag behind in the number of charging stations and in the level of related tax reliefs. The result is very low sales of electric vehicles. The share of electric cars in newly registered cars in the Czech Republic is 0.3 percent, in Europe it is over one percent. Despite this, the situation in our country is changing. According to the survey, 621 public chargers were available in the Czech Republic at the end of the third quarter of last year, fewer were only in Romania, Slovakia and Greece. The situation in western countries is completely different. At the end of last September, there were 43,730 public charging points in the Netherlands and 12,337 in Norway. In neighbouring Austria, which is comparable to the Czech Republic in terms of country area and population, there were 4,172 charging points, almost seven times more than in our country. In 2019, 5.7 percent of all newly registered vehicles across Europe were electric. The number of registrations of electric vehicles (including plug-in hybrids) increased by an average of 60 percent year-on-year last year. The countries with the largest increases are Luxembourg (+ 154 percent), Ireland (+ 127 percent) and the Netherlands (+ 120 percent). The number of public charging stations in Europe has grown by 73 percent in the last year. In total, there are already over four thousand places with fast charging in all monitored countries [12]. On average, drivers of electric vehicles are taxed at the level of 60 percent compared to users of conventional vehicles, in our country it is 80 percent. In Austria, Greece, Ireland and the United Kingdom, drivers of electric cars are even completely exempt from taxes. In Romania and Slovakia, on the other hand, drivers of electric vehicles pay higher taxes than those who drive cars on fossil fuels. In addition, the sales are less and less affected by deliveries of vehicles to pilot projects, especially energy companies, and the share of deliveries to ordinary customers on the part of both companies and households is growing [17].

5. Conclusions

This paper dealt with the analysis of using passenger cars in the business of individuals and legal persons in the Czech Republic in the context of developments and trends, including selected issues of accounting and tax aspects. The method of acquisition of a personal vehicle and the moment of ownership transfer play an important role in including the vehicle in the business assets of the business entity, putting it in use and the method of application of related costs, or more precisely expenses related to its operation and use. Today, we cannot imagine doing business without using cars. In the Czech Republic, the method of acquisition in the form of a loan or operational and financial leasing is currently preferred. Accounting and tax aspects in connection with the recognition and use of passenger cars are different depending on the methods of acquisition and raise a number of questions and ambiguities. The car can also be an important tool for tax optimization for entrepreneurs, so it is important to consider and select the most appropriate option for each accounting entity. A growing trend in the use of electric cars can be expected in the future. It can therefore be expected that in the coming years the interest in electromobility will continue to grow, and its commercialization will gradually take place. The commercial development of electromobility cannot be perceived in terms of the rapid displacement of conventional fuels in electromobility, but as an evolutionary process where different fuels, including alternatives, find application in different market segments and their relationship is complementary rather than competitive.
References


Use of Software for Licence Plate Recognition in Road Traffic

B. Kotkova

Tomas Bata University in Zlin, Nad Stranemi 4511, 760 05 Zlin, Czech Republic, E-mail: b_kotkova@utb.cz

Abstract

Road transport is currently constantly growing, and with it the requirements for its safety. Especially for further construction, reconstruction or regulatory measures, for example in cities. The basis for any of these requirements must be based on traffic flow forecasts that monitor and simulate future traffic flows. The article deals with the acquisition and use of information using software recognizing car license plates to increase traffic safety. The data obtained from these systems are widely used. By obtaining sufficient accurate data on individual vehicles and their routes, it is possible to determine, in addition to the intensities of traffic flows between individual sources and destinations of roads, also the characteristics of traffic flows, such as cruising speed, density, composition. Furthermore, indicators of the traffic situation in the monitored area depend on previous values, such as detour routes and with their help to prevent or significantly reduce the risk in traffic.

KEY WORDS: analysis, camera, car, car license plates, prediction, road transport, safety, software, traffic.

1. Introduction

It is necessary to have very good data for planning and modeling possible situations that may occur in road transport. These can be obtained from either previous surveys or new surveys. We can also use data obtained for other purposes, but containing the necessary parameters. Emphasis must be placed on accuracy, truthfulness, and verifiability. Methods used for planning and forecasting road traffic are directional surveys. There are several types, but their reliability and deviation from reality differ. The most reliable method is to register car registration marks. There are several ways to perform this method. The choice of specific ones depends on the necessary equipment, financial resources, and time possibilities of the subject.

The first option is to record registration marks in forms created according to the requirements of the individual survey. The obtained data must be transcribed into an electronic database. However, this method is demanding both in terms of the number of people writing and transcribing and the time required. Another negative factor is the inability to verify the correct way of writing both in the phase of reading marks and transcribing data into electronic form. The result may then be skewed to a certain, unpredictable extent. In addition, in the case of a multi-lane road, it is necessary to modify the counters or the system of their work so that the designated worker dictates and writes the next one.

The second variant of conducting research is to dictate registration marks into a voice recording device. This option is less demanding on the number of employees. However, the risk of distorting information remains inattentive. It should be borne in mind that road noise can also negatively affect the result, especially during subsequent transcription. Among the newer methods enabling the use of computer technology is the recording of traffic flows using a video camera and then manually rewriting the registration marks in the database from the video recording. In addition to the lower demands on the number of employees, there is the possibility of retrospective control of the survey and the elimination of errors.

The third option is to use a video camera and a computer to recognize the registration marks directly on the real-time communication and store them in a database. The research itself is then carried out by a specialist, a source of electricity, a camera, and a computer equipped with the necessary software for recognizing registration marks. If the hardware and software settings are done well, the reliability of this method is high. Unfortunately, the acquisition of the necessary equipment is financially demanding and there is still the impossibility of retrospective control of the obtained data - the transcription is performed during the survey itself.

Thus, the best way to eliminate both of these negative factors is to use software that can recognize vehicle registration marks from video recorded on the monitored road. This solution is easy to operate, highly reliable, traceable, and affordable. The survey is safe, it is possible to record more lanes of one traffic flow, the number of required workers is minimal and the evaluation of the reliability of the record can be verified. The obtained data then contains all important data: registration marks, exact transit time, vehicle speed. However, much more data can be obtained from the record, depending on the specific software that has been selected for this purpose. The following article discusses the possibilities, comparison, and reliability of individual software. It also deals with the description of how individual systems work, the requirements for their settings and accuracy also describes the most common errors leading to inaccuracies in the data obtained.

2. Software for License Plate Recognition

Today, there is already a lot of software on the market that can read, store, and process the vehicle registration
number and other data about it. It is therefore very important to clarify in advance what information we require to obtain about their later use. This can be either commercial only or interfere with security. In commercial use, this software can be used, for example, for a license plate registration system in a large shopping center. The task can be to identify vehicles arriving and departing from the center, to find out at what time intervals, so that the ideal length of time for free parking can be determined. Another very important function is the possibility of supervising possible vehicle collisions and their identification, tracing crime (stealing specific vehicles). The requirement for the system is therefore obvious - the ability to automatically recognize vehicle registration numbers, store them in a central database. This database then has other extended possibilities of marketing use - it provides various statistics of traffic by district, the number of repeated visits, and length of parking.

The next level is the use of the system, for example, city institutions, where it can be used to identify license plates, the direction of travel, color, manufacturer, type, and in some cases a specific vehicle model.

FF Group has developed an application that runs directly in the camera. The possibilities of traffic use of the TraFFic CaMMRa application are really wide, from traffic monitoring through counting and data collection to automated toll collection. It can detect trucks driving outside the permitted period, detect violations of regulations, such as overtaking in a full line or driving in the wrong lane or even search for stolen cars. In the next phase, the application will also learn to measure the speed of the vehicle, which will open up another wide field of activity. The TraFFic CaMMRa application is currently being tested by three Czech cities (Fig. 1) and is running as a pilot project in another 9 countries in Europe and South Africa [1].

![Fig. 1 The AXIS Q1700-LE camera specializes in license plate recognition](image)

A special level is the use of registration plate recognition systems to increase road safety. In road transport, there is currently a large increase in its use, which leads directly to increased demands on its structure, articulation, and safety. It applies to all types of roads, including motorways. This creates the need for software to estimate the traffic situation, which will provide a complete picture of the traffic situation in real-time [2]. The installation of these systems and the collection of data from them will create a wide database that allows you to predict the future development of traffic flows and their needs. In the case of reconstructions, detours, and accidents, it is also possible to determine the most suitable alternative route so that there are no traffic jams, congestion and thus increase the risk of minor collisions or serious accidents. Traffic prediction is one of the most important ways to increase the overall efficiency and safety of all modes of transport.

### 3. System Options and Necessary Equipment

The license plate recognition system works in such a way that the relevant camera system continuously captures the designated area where the vehicles pass or stop in front of the barrier. The registration mark is constantly recognized in the image, and if it is found, the data is stored in the database. The read registration mark is then saved together with other information such as the current date, time, and photos.

The system can also be used in mobile or outdoor applications. Images, video, and recognized data are further transferred to a central repository, where the designated worker can further process them according to requirements and purposes set in advance.

Options of available systems:
- the software can be integrated into standard camera systems;
- barrier opening according to a pre-created list of allowed registration marks;
- designation of vehicles with permitted and prohibited entry;
- export and import of a database of known registration marks;
- the known number plate can be supplemented with a photograph of the vehicle, the name of the driver, etc.;
- possibility of monitoring the time when the vehicle is in the building;
- measurement of section speed of vehicles;
- registration number recognition at different vehicle speeds.

It is very important to choose the right components of the systems and the possibilities of their interconnection. Cameras must be of high quality, their image must be sharp enough to provide the best possible options for the correct identification of the registration mark. The software must also be able to recognize the license plate at lower and higher vehicle speeds from several consecutive images.

Necessary equipment:
- license plate recognition software;
- available technology for video recording and necessary accessories;
- computer technology for video analysis.

4. Vehicle License Plate Recognition Systems in our Market

There are many plate recognition systems available on the Czech market. They differ in the amount of information that can be obtained from the records obtained, the complexity and individual equipment and components of the system, as well as the price. Here are at least some of them along with a short specification:

- **ATEAS Security s.r.o. (LPR Engine)** The LPR Engine is a vehicle license plate detection and recognition module that complements any edition of ATEAS Security. This module is designed for powerful license plate recognition of vehicles with a connection to the existing event control in the system. Approximately 50 different national and other vehicle license plate systems are supported.

- **NITTA Systems s.r.o. (AVS)** The automatic entry system is a comprehensive system that solves the registration of arrivals and departures of vehicles to closed race areas, or automatic monitoring of movement around the area. It is based on license plate recognition from the image captured by the camera.

- **CAMEA** The system automatically detects the vehicle with the registration plate in the field of view of the camera and then reads the license plate. These processes take place in real-time and the resulting recognized mark is available immediately after vehicle detection (within 1 sec). The device can recognize license plates/license plates with a high probability. The angle between the camera and the license plate can be up to $\pm 30^\circ$.

- **ControlTech (InSignia 4)** License plate identification and recognition are based on Zamir's LPRware scanning and text recognition technology. The system is equipped with a scanning sensor that, in the event of a vehicle passing through, records a series of photographs and passes them on for processing. The registration mark is automatically detected in the photos, and then the individual characters are recognized and converted to digital form.

- **GeoVision (LPR)** The system works on the principle of optical text recognition. The system can search for and read the vehicle registration number in the scanned scene and work with the data obtained in this way in text databases.

- **Alimex (Altex-LPR)** The system works with digitized images of vehicles, which are converted to JPG or BMP format. Using the OCR function, it recognizes the license plate and converts its value into characters that are processed in the control software. The SW solution itself contains a library of all available types (fonts) of used registration marks throughout the European Union and most countries of the world.

- **Designa**: The integrated registration mark identification system enables their automatic recognition in the PM ABACUS system. These markers are automatically read at the entrance using LPR and converted alphanumerically using the image recognition method [3].

The individual systems differ, as mentioned above, mainly in the technologies used. Furthermore, the amount and type of information obtained and stored, as well as financial availability.

The most common errors that can occur with individual software due to incorrect operation or settings:
- the number plate of the second vehicle is covered by another passing vehicle in the engagement;
- the registration mark is illegible but incomplete. It is not possible to determine the last symbol read;
- the license plate is illegible due to the shallow depth of field;
- the number plate in the picture is not clear enough concerning the location;
- the number plate is not legible about the speed of the moving vehicle;
- the license plates present a low contrast when using a camera with low dynamics that eliminates car lights;
- registration marks merge with the background;
- registration marks when causing short distances with a wide lens cause geometric distortion.

The location and type of camera used directly affect the reliability of the correct reading of the registration plate. Thanks to the right combination, you will achieve a high level and accuracy of a reading. The whole registration mark must have a size of min. 130px, standard size plate = $520 \times 110$ mm. The size of the scene corresponds to a calculation of 250px / 1 m. Calculation = $1920/250 = 7.68$ meters (width of view). The visualization shows the width and distance of the reading when using a camera with FullHD resolution (focus 16 mm) (Fig. 2) [4].
5. Methods of Systems for Reading Registration Marks

Automatic registration and reading systems for registration marks work with algorithms. Used to find registration marks in the image. In the Czech Republic, the registration mark consists of five to seven alphanumeric characters. Each registration mark must contain at least one letter and at least one digit. The first letter indicates the code of the region in which the SS was issued. Covering, soiling, or tampering with the mark, making it impossible to read it, either intentionally or unintentionally, is strictly prohibited. For driving with a damaged brand, there is a fine of five to ten thousand crowns and a ban on driving for six to twelve months [6].

Here are the most commonly used algorithms for finding registration marks in an image:

The algorithm based on contour search - first the input frame is thershed and the result is a binary image. The principle of mathematical morphology-closure is used for this, the task of which is to close missing places in objects [8]. Then the outline of the object is searched. A rectangle is created around it and it is compared whether it matches the size of the registration mark character. If the appropriate number of characters is not found, the size of the closure core must be changed. The disadvantages of this algorithm include that thresholding segmentation depends on the same lighting conditions throughout the brand. This must not be geometrically rotated, have characters close to each other. These must also be free of cracks. Characters are searched throughout the input image [8].

Edge detection algorithm - this algorithm is based on the detection of vertical and horizontal edges. The main part of the algorithm is the use of the Laplace operator to find vertical and horizontal edges. In the case of a connection, only vertical edges are searched. Noise must be removed from the image. Subsequently, objects with similar dimensions are searched. If there are multiple groups of objects in the slide having similar ones coordinates whose correct frequency is considered to be correct (Fig. 3).

To distinguish objects that belong to a mark and those that do not, the median distance of the individual objects must be determined. Objects that exceed this median must not be counted as part of the mark. The distance thus calculated is not counted as part of the mark [9]. Again, a list of disadvantages of the algorithm: the mark must not be geometrically rotated, great emphasis is placed on the correct setting of the camera and because we detect only characters, there is a possibility of confusion, especially in the case of company labels on the car.

The system works longer with the method of optical character recognition - OCR (Optical Character Recognition). This method automatically identifies the characters in the bitmap. There are several methods for OCR, in which we detect different characteristics of characters by extraction. The risk of noise, distortion, and rotation must be taken into account. Different methods also have different procedures and therefore the input data requirements differ. However, the task of character recognition remains the same for everyone [10].

6. Testing the Correctness of Reading Registration Marks using an Algorithm

Experimental testing was performed on 336 images that captured different scenes. For example, pictures were taken at dusk or on a sunny afternoon. For the closest possible approximation to reality, images with one-line and two-line registration marks are included. Furthermore, dirty, damaged, spatially rotated license plates, as well as cars with many advertising signs. In addition, there are images with one or more registration marks.

Evaluation criteria were set before the evaluation function. The correctness of the proposed method was evaluated on the basis of observations, where only the one that could be read by the observer of the image and at the same time was
not read correctly by the proposed method will be considered a badly read mark. In the case of multiple identifications of the same SS in one frame with each time different result, the worst possible detected will be taken. Let \( P \) be a registration mark and \( S = \{P_0, P_1, \ldots, P_n\} \) is the set of all registration marks in the test frames. We determine the effectiveness using the formula:

\[
C(S) = \frac{1}{n} \sum_{i=0}^{n-1} h(P_i)
\]

(1)

where \( n \) is the size of the set (cardinality) and the function \( h \) determines the correctness of the given recognition brands. The function \( h \) computes correctly recognized characters using the relation (2):

\[
h(P) = \frac{a}{b}
\]

(2)

where \( a \) is the number of correctly recognized characters in the \( P \) mark and \( b \) is the total number of characters in the \( P \) mark.

Efficiency testing was performed on a Macbook pro (model MD101xx / A), which has a 2.5 GHz Core i5 processor and 4GB of DDR3 ram memory. The processing of one image with a resolution of 640 \( \times \) 480 took an average of 0.14 s. The algorithm could not find 6 registration marks out of 347. In total, 63 characters were not recognized, of which 42 due to no registration marks found. Duplicate registration marks were detected in 4 registration marks, where one character differed after reading. Most often, similar characters were incorrectly read, such as B for 8.0, for D, 6 for S. The efficiency calculated by the formula (1) is 97.4%.

Emphasis was placed on the design and construction so that the algorithm could read as many practical situations as possible. This was achieved, for example, by equalizing the histogram to read an image taken at dusk. Furthermore, thanks to the adaptive thresholding, it is not so problematic to recognize a registration mark on which a shadow appears in part. A full test was used in the algorithm to minimize false detections. A slight affinity rotated registration mark does not pose a problem to the algorithm because it can balance it. All objects that did not represent characters were removed from the registration mark. For accurate recognition of registration mark characters, a neural network has been built, which can very accurately determine which character it is, in addition, thanks to the possibility of learning, a poorly recognized character can be added to the training set. Thanks to the design of the algorithm, the efficiency of the algorithm was 97.4% on the test set. Most test shots have a resolution of 640x480 and the algorithm was able to read license plates on the Macbook for an average of 0.13s. This time is sufficient for image processing, but when processing video, it can recognize approximately 8 frames per second. Therefore, every third frame was processed to achieve real-time video processing with 25 FPS [5].

7. Conclusions

Automatic license plate reading systems have been developed primarily to increase road safety and data acquisition to create safety forecasts. Systems are also often used to control compliance with road traffic rules, such as red light control, crossing a solid line, unauthorized use of a bus lane. If two control camera stations are available, it is possible to check compliance with the maximum permitted speed, knowing their mutual distance. Other possible uses are border controls, collection of road taxes, tracing of stolen vehicles. They can also be used in the private sphere to control the entry of vehicles into certain areas. The system keeps track of which vehicle entered the premises and when and when it left. The codes can be linked to a database of authorized persons and access to the area can be allowed or denied accordingly. This can be used for parking systems, airports, shopping malls, etc. to alert drivers who have not paid for fuel at petrol stations and much more.

One of the major weaknesses of these systems is the large number of variables that interfere with the recognition process itself. All these variables must be considered when implementing and installing the system, and their effect on the recognition quality should be suppressed as much as possible. The influencing variables include, for example, the distance of the mark from the camera, the angle at which the camera captures, the lighting conditions, the contamination of the license plate, the location of the mark, and the speed of the moving vehicle. The key factor that deteriorates the quality of the ANPR system is image quality. For example, blurred images reduce the efficiency of systems, so special techniques are needed to reduce exposure time. Other factors that reduce the effectiveness of recognition systems include poor brand lighting, low contrast, shadows, poor camera quality, foreign vehicles with other brands, and more.

Further development of these systems will certainly be aimed at further improvement and expansion of the required functions. At the same time, however, it is necessary to clearly define the limits that should minimize the abuse of these systems and the restriction of possible freedoms of the individual.

Acknowledgments

This research was based on the support of the Internal Grant Agency of Tomas Bata University in Zlin, the IGA / FAI / 2020/003 project and the Institute of Safety Engineering, Faculty of Applied Informatics.
References

1. Three Czech cities are testing smart cameras that recognize the license plate, color and vehicle manufacturer
   Available from: https://www.systemonline.cz/zpravy/tri-ceska-mesta-testuju-chytre-kamery-ktere-rozpoznaji-spz-
   barvu-a-vyrobce-vozidla-z.htm


   in Prague

4. Do you know how to work with the NumberOK system? 2016. Available from: http://www.abbas.cz/clanky/recenze-
   technika/vite-jak-pracovat-se-systemem-numberok/

5. Gluc, M. 2014. Car License Plate Detection and Reading License Numbers, Technical University of Ostrava


7. Krajicek, P. 2010. License plate / registration recognition, BUT, Faculty of Electrical Engineering and
   Communication Technologies, Department of Automation and Measurement Technology, Brno.

   in Night time Vehicle Image, Chonbuk National University, Dept. of Electronic Engineering Chonbuk,
   ITConvergence Research Center, Korea.

   and Communication, 2016.

    Technology, Faculty of Mechanical Engineering.
The Nadal Criterion Study in a Passenger car with Independently Rotating Wheels

G. Vaičiūnas¹, S. Steišūnas², J. Dižo³

¹Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, E-mail: gediminas.vaiacinas@vgtu.lt
²Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, E-mail: stasys.steisunas@vgtu.lt
³University of Žilina, Univerzitná 8215/1, 010 26, Žilina, Slovak Republic, E-mail: jan.dizo@fstroj.uniza.sk

Abstract

Authors of an article compare the dynamic characteristics of cars with integral wheel sets and wheel sets with independently rotating wheels by comparing the Nadal criterion values and their laws of change when the car runs on various curves and straight sections of the railway. The studies show that in curves of a low radius, laws of change of the Nadal criterion values are fundamentally different than in straight railway sections; it has a significant impact on the comparison of dynamic properties of passenger cars with integral wheel sets and wheel sets with independently rotating wheels.

KEY WORDS: passenger car, independently rotating wheels, dynamic characteristics, the Nadal criterion

1. Introduction

As far as the railway exists, there are issues of rolling stock derailment and various related researches [1-3]. The scientists study the influence of rolling stock wheel flange conicity and wheel impacts on train derailment [4]. The research of this influence makes an assumption that the process of wheel flange “climb’’ on rail head is quasi-static. In such case, the criteria of wheel flange “climb’’ during derailment would be obtained by analysing the forces acting on the wheel sets [5-7]. One of the research subjects is the classical derailment equation [8] that describes the frictional slip between the wheel and rail. Another subject of research is so-called approximate analytical formula [9] that describes the effect of wheel/rail scroll forces. Laboratory researches of the “climbing’’ of the flange of one wheel set wheel during derailment performed on the bench by Chinese researchers confirms the results of the theoretical analysis. The derailment due to wheel impacts is investigated as a type of dynamic derailment. The criteria of derailment are provided by considering wheel jump height, transverse impact force and vertical load on the wheels. Analysed factors: speed of wheel set side impact, wheel flange angle, wheel/rail friction coefficient, vertical load on the wheel and impact time interval during wheel set derailment [10]. It is difficult to detect phenomena such as rail swell, noise, derailment, etc. in low radius (180–300 m) railway sections with large difference in rolling radiuses of the inner / outer wheels of wheel set [11]. The effect of a car wheel and rail friction modifier on road curves was investigated and its impact on car rolling was established. The world of science focuses on investigation of a damaged wheel (for instance, skating). It is also interesting but somewhat different aspect of the study [12, 13]. There are also studies where the dynamics are investigated in the context of other quality indicators of the car [14].

An objective of the following study is to examine the dynamic characteristics of cars with integral wheel sets and wheel sets with independently rotating wheels by using available scientific expertise and computer equipment, as well as answer the question whether these properties are adequately reflected by the values of the Nadal criterion when the car runs on different railway curves and straight sections, respectively.

2. Methodology of the Study

Computer simulation with “Universal Mechanism“ (UM) software package was selected for the research for several reasons. At first, the researches with computer model do not waste railway resources. The researches with this software package allow performing many more researches in a relatively short time compared with researches using real rolling stock. Research limitations are also one of the main reasons why simulation has an advantage over field testing: the researches with this software makes it possible to see which speed, angle of curve or other factor affecting stability is limiting or dangerous. UM software package can check the critical speed of not only one car but also the whole train. The software allows analysing vehicle dynamics depending on wheel and rail profiles, rolling stock suspension, chassis and railway parameters.

The passenger car model consists of a body, two bogies and four pairs of wheel sets. The bogie consists of two parts of a spring suspension, two side beams and two wheel sets. The body of a passenger car model is mounted on two-axle bogies. The bogie frames are connected to the wheel sets through the primary suspension elements and connected to the body through the secondary suspension elements. A passenger car structure is modelled with two types of wheel sets: with integral wheel sets provided in Fig. 1 and wheel sets with independently rotating wheels provided in Fig. 2.

Wheel set provided in Fig. 1 has six degrees of freedom that allow the entire wheel set to rotate and move in X, Y and Z axes. Wheel set with independently rotating wheels is provided in Fig. 2.
The wheel set provided in Fig. 2 is not integral and consists of 4 parts: axle, two wheels and bearing. The wheels of this wheel set can rotate independently, thus the mechanism has seven degrees of freedom. The wheel profiles of both types of used wheel sets are the UIC510-2 type profile. The bogie provided in Fig. 3 consists of two wheel sets, a frame, four axle boxes and a double spring suspension.

Technical characteristics are provided in Table.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car body mass, kg</td>
<td>54 700</td>
</tr>
<tr>
<td>Wheel set mass, kg</td>
<td>2000</td>
</tr>
<tr>
<td>Moment of inertia of car body masses by x axis, kg · m</td>
<td>50 000</td>
</tr>
<tr>
<td>Moment of inertia of car body masses by y axis, kg · m</td>
<td>30 000</td>
</tr>
<tr>
<td>Moment of inertia of car body masses by z axis, kg · m</td>
<td>30 000</td>
</tr>
<tr>
<td>Moment of inertia of the wheel set masses by x axis, kg · m</td>
<td>1 200</td>
</tr>
<tr>
<td>Moment of inertia of the wheel set masses by y axis, kg · m</td>
<td>200</td>
</tr>
<tr>
<td>Primary suspension stiffness coefficient in the horizontal direction, N/m</td>
<td>1·10⁶</td>
</tr>
<tr>
<td>Primary suspension stiffness coefficient in the vertical direction, N/m</td>
<td>1·10⁶</td>
</tr>
<tr>
<td>Secondary suspension stiffness coefficient in the horizontal direction, N/m</td>
<td>2·10⁴</td>
</tr>
<tr>
<td>Secondary suspension stiffness coefficient in the vertical direction, N/m</td>
<td>2·10⁴</td>
</tr>
<tr>
<td>Suspension type</td>
<td>Spring with hydraulic dampers</td>
</tr>
<tr>
<td>Distance between automatic clutches, mm</td>
<td>2 475</td>
</tr>
<tr>
<td>Wheel set base, mm</td>
<td>2 400</td>
</tr>
<tr>
<td>Body width, mm</td>
<td>2 218</td>
</tr>
<tr>
<td>Body length, mm</td>
<td>3 920</td>
</tr>
<tr>
<td>Wheel rolling radius, m</td>
<td>0 475</td>
</tr>
<tr>
<td>Half sleeper width, m</td>
<td>1 2</td>
</tr>
</tbody>
</table>

During the car simulation, it is assumed that all bodies are rigid and can move in X, Y and Z axes. During the computer simulation with the passenger car model created in the "Universal Mechanism" software, all suspension elements were adapted for integral wheel sets only (Fig. 4, a), thus, after having replaced the type of wheel sets with independently rotating wheels, the passenger car model was left without any suspension elements except the suspension frame (Fig. 4, b).
Fig. 4 Passenger car model suspension in “Universal Mechanism“ software: a – the model with integral wheel sets; b – after replacement of model wheel set type with independently rotating wheels

During simulation of the suspension with independently rotating wheels, it was possible to simulate the same construction and same parameters as in the model of a passenger car with integral wheels. Horizontal and vertical irregularities in 1000 m section of a modelled track are provided in Fig. 5.

Fig. 5 a Vertical irregularities of a modelled track

Fig. 5 b Horizontal irregularities of a modelled track

Track irregularities provided in Fig. 5 were measured in real UIC 60 railway and were selected from the list of track irregularities provided in “Universal Mechanism“ software package. These track irregularities were selected because they also correspond to the real irregularities of the selected rail profile. Considering the track curve parameters provided by the author [15], 200 m and 2900 m radius track curves were designed (provided in Fig. 6) to determine the minimum and maximum speed in the curves. In order to determine the maximum speed in straight sections, 1000 m length straight section was designed.

Fig. 6 Curve geometries of the modelled S type: a – when $R = 200$ m; b – when $R = 2900$ m
The calculations of the stability criteria are performed by estimating the contact forces of the wheel and rail (provided in Fig. 7 below).

The Nadal criterion is widely used for derailment. It takes into account the shape of the wheel set wheel, the contact angle and the coefficient of friction, but it does not take into account the longitudinal forces and angle of curve where it is moved [16]. The Nadal criterion is calculated according to the formula [17]:

\[
q_0 = \frac{F_y}{F_z} = \frac{\tan \delta - \mu_y}{1 + \mu_y \cdot \tan \delta},
\]

where \( \mu_y = \frac{F_y}{N} \); \( \delta \) – contact angle.

3. Research Results

During the simulation, the maximum values of the passenger car Nadal criterion were calculated to determine the maximum speed of passenger car models during movement in 200 m, 2900 m radius “S” type curves and in the straight track section. Calculation results are provided in Figs. 8-10 respectively.

The chart provided in Fig. 8 shows that the passenger car model with the independently rotating wheel (IRW) in the 200 m radius curve has lower maximum Nadal values when moving at the speed range from 45 km/h to 80 km/h and ~ 90 km/h than the model with the integral wheel set SW. At all other speeds of movement, maximum Nadal criteria values of the model with the integral wheel set SW are lower than the model with the independently rotating wheel IRW. The model with the independently rotating wheel IRW reached the largest permissible Nadal criterion value at the speed of 95 km/h, when the maximum established value of the model with the integral wheel set SW is 0.65 at the same speed. The model with the integral wheel set SW reached the largest permissible Nadal criterion value at the speed of 107 km/h.

![Fig. 8 The maximum Nadal criterion values in the 200 m radius curve](image-url)
Fig. 9 The Nadal criterion values in the 2900 m radius curve

The chart provided in Fig. 9 shows that the maximum Nadal criterion values of the passenger car model with the integral wheel set SW are lower compared to the model with the independently rotating wheel IRW at all established movement speeds in the 2900 m radius curve, unlike the graphs provided in Fig. 9. The model with the independently rotating wheel IRW reached the largest permissible Nadal criterion value at the speed of 200 km/h. The model with the integral wheel set SW reached the largest permissible Nadal criterion value at the speed of 255 km/h at the same section.

Fig. 10 The Nadal criterion values in the 1000 m length straight section

The chart provided in Fig. 10 shows that the maximum values of the passenger car model with the integral wheel set SW are lower compared to the model with the independently rotating wheel IRW at all established movement speeds, as it is provided in the graphs in Fig. 10. The model with the independently rotating wheel IRW reached the largest permissible Nadal criterion value at the speed of 205 km/h. The model with the integral wheel set SW reached the largest value at the speed of 290 km/h at the same section.

4. Conclusions

One of the easiest methods to compare the dynamic characteristics of cars with integral wheel sets and wheel
sets with an independently rotating wheel is to compare the Nadal criterion values of the car running through various railway curves and straight sections. Research performed by the authors has shown that this method is operative.

After having the calculated Nadal criterion values, it was found that as the speed of the car increases in the straight section, the values increase with a regularity close to the linear, however, the Nadal criterion values for wheel sets with the independently rotating wheel are approximately twice as large as for the car with integral wheel sets.

Regularity of the distribution of the Nadal criterion values is totally different in 200 meters radius railway curves compared to straight sections. In such case, the Nadal criterion values for wheel sets with the independently rotating wheel are lower than the values for the car with integral wheel sets, when the speed is less than 70 km/h.

To sum up the results of study, it can be stated that the use of available scientific expertise and examination of dynamic properties of passenger cars with integral wheel sets and wheel sets with independently rotating wheel with computer software helped to find that the Nadal criterion values largely reflect these properties under the various running conditions of the car.

The possible direction of further studies is to examine the chassis dynamics of a passenger car by selecting such values of damping and stiffness of the primary and secondary suspension of the car that the Nadal criterion values would be permissible for the car with an independently rotating wheel in the widest possible speed range.

References
Testing of the Reliability of Vehicles Monitoring in a Selected Region

M. Boroš¹, Š. Jangl²

¹University of Zilina, Faculty of Security Engineering, Univerzitná 8215/1, 010 26, Zilina, E-mail: martin.boros@fbi.uniza.sk
²University of Zilina, Faculty of Security Engineering, Univerzitná 8215/1, 010 26, Zilina, E-mail: Stefan.jangl@fbi.uniza.sk

Abstract

Vehicles monitoring due to the boom in information technology is gaining considerable interest in both the commercial and private spheres. Undoubtedly, car factories, which place one of the two most commonly used technologies in cars directly in production, have a positive effect. These technologies include the Global System for Mobile Communication - GSM and the Global Positioning System - GPS.

Vehicle monitoring can be understood as communication between a transmitting unit placed in a car and a receiving device, which may be in the form of cloud storage. It is then possible to connect to the repository using various desktop or mobile applications in which it is possible to monitor various indicators. The most common ones are the real speed of a monitored car, distance traveled, fuel consumption, or the current time. Several companies on the market have technologies in their portfolio designed for vehicle monitoring. The main aim of the paper is to perform experimental testing of the reliability of selected products intended for vehicle monitoring. Among other things, we will focus on the quality of the track record, which will be created by the application belonging to the selected product. Experimental testing will be carried out along the roads of the Zilina Region. Experimental testing represents a partial part of a comprehensive investigation of vehicle monitoring options.

KEY WORDS: monitoring, testing, vehicles, GPS, reliability, region.

1. Introduction

We consider the global system for mobile communication, hereinafter referred to as GSM, to be the second generation of mobile systems, the so-called 2G network, whose main idea was the transition to a digital system. GSM has been in commercial use since 1991. At present, there are several frequency variants of this system with the designation GSM 900/1800/1900. These values are a numerical expression of the approximate frequency on which the GSM network operates. For Europe, the standard used is 900 MHz, while in North America it is 1900 MHz. GPS, or Global Positioning System, is based on mutual communication between satellites and devices on Earth [1-2].

Both GSM and GPS are key components of the car monitoring process. The GPS module plays an important role in determining the position of the in-vehicle monitoring unit based on the mutual communication between the Earth-based monitoring device and the orbiting satellites in space. The GSM module can simply be understood as an intermediary of information between the monitoring unit in the car and the person using the monitoring services. It must include a SIM card with which it sends notifications in the form of SMS or e-mail about events via mobile telephone networks. Car monitoring has many uses in practice. It represents the protection of the vehicle against theft, the way of checking employees during work duties, the image of the driver's driving style, but it is also used in special types of cars, such as vehicles for transporting dangerous goods, transporting money, military vehicles, ambulances, fire engines, and police cars [1, 3, 4].

The whole system has three basic components - space, control, and user. The cosmic component consists of satellites orbiting the Earth, the purpose of which is to signal the entire surface of the planet Earth. 21 satellites are actively performing their functions and the other 3 are active backups, which means that they are ready to immediately replace one of the active ones if necessary. The satellites move around the Earth at a speed of 11,300 kilometers per hour, at 20,190 kilometers from the Earth's surface, along 6 circular orbits with an inclination of approximately 55°. Some satellites are protected against an electromagnetic pulse that can be caused by the explosion of an atomic bomb; others have sensors capable of detecting a nuclear explosion. The movement of satellites is ensured by two main components [5, 6]. The first is solar panels, which provide the necessary energy, and the second is fuel supplies for jet engines used to correct the trajectory. The control component of the system consists of control centers, whose task is to control the operation of satellites [7]. The Master Control Station is in the state of Colorado in the United States. The user part of the system consists of the receivers themselves, capable of communicating with satellites. Thanks to the user folder, users can track their location on the map. All three components of the GPS are shown in Fig. 1.
2. Methodology

Reliability testing is an essential part of proper system operation. In the case of GPS monitoring of vehicles, it is necessary to regularly test the reliability of the displayed location and in terms of information about the position of the vehicle [8].

In the case of our testing, we decided to test the monitoring unit ONI system from the company NAM Slovakia marked NCL21. In the case of practical reliability testing, we focused on the basic functions that the system offers in our selected region. These functions include the history of the vehicle's position, real-time monitoring, the possibility of setting zones, and a web or mobile application. During the experimental testing, we drove the vehicle almost 1000 km, while adhering to the principles of safety of traffic and inhabitants of the region [9-10].

The selected region was the district of Martin, also called Dolný Turiec, which is part of the sought-after region of Slovakia called Turiec. The Martin District is one of the eleven districts in the Žilina Region. Martin District has an area of 735.65 km2. The Martin district is shown in Fig. 2 within the Žilina region.

![Fig. 2 Location of the Martin district within the Žilina region](image)

During the testing, two operating modes of the monitoring unit were used. The first mode consisted of continuously sending information about the current position and speed of the vehicle every five seconds and was used to monitor the vehicle in real-time. The second operating mode was based on sensing the position every ten seconds and the position data was sent once a minute. Monitoring was activated at the time of motion detection. In case of standing, the battery is switched off to save money. For these conditions, we were able to test the system on a single charge for ten days.

3. Results

One of the basic functions that must be fulfilled by the control unit of the monitoring system is the position history, which is used to check the route traveled or to follow the route plan. For transport safety, this function is very important in the event of a crisis associated with transported valuables [11].

Determining the position history with the NCL 21 is easy, and after entering the driving time and driving date, the route corresponding to the entered information is displayed as in Fig. 3. The display in Fig. 3 comes from the web interface and fully reflects the route we traveled two days before searching.
Another parameter we tested was real-time car tracking. In addition to determining the real position, it is possible to monitor the temperature in the vehicle and the speed at which a vehicle is moving. Such monitoring can be carried out as control of company cars to determine the effective use of the company’s finances, for company vehicles [12]. During the experimental tests, we checked the current position 38 times using a mobile application. In 36 cases the system displayed the exact position, in the other two cases the position of the car was shifted by about 200 meters. These places were situated in a more mountainous environment where weaker GPS signal coverage is probable.

Zone settings are a very important feature that not all GPS monitoring systems have. Thanks to it, it is possible to have information about the illegal movement of the car. This function can also be used within the critical infrastructure to prevent the emergence of crises [13-15]. The entry of the car into the selected zone, resp. leaving it will cause an immediate notification of this fact via a notification from the application. The text of the message can be freely set to ensure security [16]. The zones can take the form of a polygon, which can be easily formed according to the user’s imagination, or the shape of a circle, the content of which can be increased or decreased as needed [17]. An example of creating a zone in the shape of a polygon is shown in Fig. 4.

The condition for setting zones is to define the rules that are associated with leaving the zone, entering the zone, standing in the zone, and speeding in the zone. It is possible to set several rules for individual zones at once. An important addition to each rule is the ability to set up notifications via SMS or e-mail. Notifications are sent to a pre-selected person whenever an event from a specific rule occurs [18]. During the experimental testing, the functionality of all types of rules and associated notifications was verified, which came flawlessly, reliably, and quickly. In total, more than 80 different notifications were received for testing purposes.
The monitoring unit performed its functions flawlessly throughout the testing period. The same conclusion can be drawn in connection with the functioning of mobile and web applications. Their motto was mainly the intuitive and clear user interface and the smooth running of all tested functions. Thus, it can be stated that the monitoring unit together with the related applications showed above-standard reliability during the experimental testing.

4. Discussion

Vehicle monitoring is becoming a part of almost every company car to effectively spend the company's financial resources for the benefit of the company [19]. In our case, we took the experimental testing of the reliability of the GPS monitoring system more complex, and, in addition to the quality and accuracy of positioning, we also focused on the possibilities offered by the manufacturer's applications. We opted for this type of experimental testing, as we can consider additional functions, after the price, as the second most important parameter when choosing a GPS monitoring system. In terms of objectivity, it would be appropriate to subject other GPS monitoring units to the same tests, but now I do not have any. Through e-mail, we contacted several companies with an offer for cooperation and independent testing, but unfortunately only NAM Slovakia showed interest in cooperation.

A new GPS monitoring system created using the Arduino platform is currently being developed at the Faculty of Security Engineering. The basic model for this system was the reliability tests of the monitoring system from the company NAM Slovakia.

5. Conclusions

The paper aimed to point out the experimental testing of the reliability of the GPS monitoring system from a comprehensive point of view. The complex aspect was chosen to gain more extensive knowledge about the tested monitoring equipment. In the past, several tests were performed on the premises of the Faculty of Safety Engineering aimed at correctly determining the route traveled. In these pilot tests, the idea of more comprehensive testing emerged, which was presented in the article.

The basic difference between classical and complex testing is the interest in additional functions. For the needs of our experimental testing, we decided to use the option of setting a polygon zone, searching for data in the history of the routes traveled, and determining the current location. We created a polygon zone around the entire Martin district and tested the violation of the conditions specified when creating the zone. In all cases, the system responded flawlessly and immediately notify us via SMS message of a violation of any of the rules. The search for route indicators such as route direction, speed, and time has been checked several times. In all cases, the correct time was shown for a position and the accuracy of the speed was +/- 5km / h which is a reasonable deviation. As part of the current location, it happened to us twice that the system evaluated another position as it was. Both cases occurred at a time when we tested the GPS monitoring unit on the edge of the mountains where it is possible to assume a weaker GPS signal strength. In other cases, in the city, on the road, the destination was accurate.

Testing the reliability of GPS monitoring systems needs to be addressed and performed regularly. We can thus state based on the current development of technological equipment and the increasingly frequent use of company cars for private purposes. In the future, we are preparing tests aimed at comparing the reliability of commonly available GPS monitoring units and our own, created using the Arduino platform, as part of the scientific research activities of the Faculty of Security Engineering. These tests are scheduled for autumn 2020.

Acknowledgment

This work was supported by project VEGA 1/0768/19 Research on impacts of the socioeconomic development of the region on the citizens security.

References

888


Critical Road Transport Infrastructure

M. Blahova

Tomas Bata University, Faculty of Applied Informatics, Nad Stranemi 4511, 760 05 Zlin, Czech Republic,
E-mail: m6_blahova@utb.cz

Abstract

The article is focused on critical road transport infrastructure. The aim is to propose a way of identifying critical infrastructure elements in road transport subsector. Disruption of transport critical infrastructure causing economic losses to natural or legal persons or the state. Critical infrastructure is defined as public infrastructure.

Part of the article is devoted to a description of critical infrastructure, a description of road infrastructure, description of critical infrastructure elements. Definitely based on cross-cutting criteria. Any object must be assessed in relation to the territory. The content of the file is a measure designed to minimize outages and mitigate the consequences of situations.

One of the chapters is involved in the process of identifying critical infrastructures, entities involved in the identification of critical infrastructure and road transport infrastructure. The final procedure is a procedure for identifying critical infrastructure elements capable of increasing critical infrastructure in the field of road transport.

KEY WORDS: EMS, Vehicle, Equipment, Diseases

1. Introduction

Critical infrastructure is the infrastructure that is key to the running of society and the economy. Its protection is important so that a crisis does not arise. European critical infrastructure is its infrastructure, the disruption of which would have an impact on the functioning of EU countries. Critical infrastructure is currently a much-discussed topic in all areas of society. Critical infrastructure is protected and well secured so that failures that could result from the failure of the infrastructure, which can have fatal effects on lives, health, property, and the environment, can be jeopardized. Disruption of critical infrastructure can cause economic losses.

Critical infrastructure includes elements of critical infrastructure that can be identified using cross-cutting and security criteria. Basic rules designating elements of critical infrastructure governing legislation and other documents published in connection with this issue. It is possible to involve the entities concerned in the process of determining the elements of critical infrastructure, which have established rights and obligations by legislation.

2. They are Involved in Determining the Elements of Critical Infrastructure

A some important entities are involved in the process of determining elements of road critical infrastructure (see Fig. 1), which can be categorized into three groups: entities evaluating and determining elements of road critical infrastructure (ie Ministry of Transport, Ministry of Interior and Government) and operators of evaluated elements (ie Roads and Motorways Directorate), or other stakeholders.

3. Patterns of Point Elements

An element representing a closed and concentrated unit, usually located on a smaller area, can be referred to as a point element. This type of element can in most cases be protected from external influences [1].
There are usually four types of point elements on motorways and roads (Figs. 2-3):

**Bridges**
A bridge is a structure that forms a link between two adjacent elements and allows passage across a river, abyss, or other roads [2].

**Tunnels**
A tunnel is an underground structure passing under an obstacle, which can be mountains, rivers, or cities, and most often serves as a passage for cars and railways [3].

**Underpasses**
Underpass means a section of the road passing under another road or railway [4].

**Railroad crossings**
A level crossing is a place where a road crosses a railway line [5].

![Fig. 2 Number of point elements on motorways and roads](image)

![Fig. 3 Length of point elements according to the type of object on motorways and roads](image)

4. Procedures for Creating Critical Infrastructure Identification Processes in Transport

There are currently several approaches to identifying critical infrastructure elements. All current methodological procedures are connected by the idea of risk management, which consists of three phases from identification, through analysis to evaluation and possible subsequent creation of measures or protection. Procedures and methodologies need to be constantly improved and simplified through graphical representations of the involvement of entities together with input
and output documents.

To create a proposal, it is necessary to analyze the existing procedures for determining the elements of critical infrastructure and the involvement of individual entities. Several approaches and methodological approaches for assessing elements in different critical infrastructure sectors are currently being developed. An analysis of four approaches to identifying critical infrastructure elements was also performed [1].

In the energy sector, a methodology has been developed to uniformly identify installations for the generation, transmission, and distribution of electricity from national and European critical infrastructure and to ensure the physical protection of such installations [6]. This methodology defines the framework of critical infrastructure issues in three phases, namely the identification, assessment, and protection of critical infrastructure elements, each of which includes a subprocess of identification, analysis, and evaluation. The determination phase is analyzed in more detail within the solved problem and leads the evaluator and the proposer to the solution process in a precise algorithm in four steps. The steps lead from the proposal to identify the critical infrastructure element, through the analysis of the underlying data, which is followed by the assessment of the proposal by the evaluation committee. In the last step, a measure of a general nature is issued for the designation of an element as an element of critical electricity infrastructure.

A methodology has been developed by the National Office for Cyber Security for the identification of elements of critical infrastructure in the area of communication and information systems,[7] which is based on the Crisis Act [8] and a government regulation [9]. This methodology assesses the element of cross-cutting and sectoral criteria from the communication and information systems sector. After meeting these criteria, set by a government decree [9], it is necessary to decide whether it is an organizational unit of the state or not.

This step is crucial for the correct identification of an element as a critical information infrastructure element. For the area of road transport, a Methodological Procedure for the identification and evaluation of critical elements of road infrastructure and their risks has been developed [10].

The methodological procedure sets out the process of identifying critical elements of road transport infrastructure in three phases and four steps. In the first phase, the elements to be evaluated are selected, and in the first step, the extent of the assessed area is determined. The second phase deals with prioritization, the second step for determining then serves to supplement the information to evaluate the transport model. The second step is, among other things, the calculation according to the set factors and criteria, which determines the weight and value of the criterion. The third and fourth steps are part of a third phase called countermeasures. Based on the calculation in the second step, a set of the most critical elements is obtained, which together with the selection of possible measures and the evaluation of the costs of the measures form the third year, called the evaluation of the measures. In connection with the last or fourth step, a plan for the implementation of measures is proposed [10-11].

5. Design of the Process of Determining the Elements of Critical Road Transport Infrastructure

The proposed process for determining the elements of critical infrastructure is based on available methodologies or procedures developed in other sectors. In creating the proposed process, not only the experience from the presented procedures was taken into account, but also the specifics resulting from the road transport environment. Within the framework of this proposal, the emphasis is placed on the improvement or improvement of individual steps in determining the elements of critical infrastructure with the involvement of stakeholders. The design of the process of determining the critical road transport infrastructure is shown in Fig. 4 using the diagram and is divided into four phases.

![Phase diagram of the proposed procedure for determining the elements of critical road transport infrastructure](image)

After the start of the process, the preparatory phase begins, marked in green in the diagram, in which it is necessary to determine the size and extent of the area (step 1), which will be the subject of subsequent assessment. This identification should be carried out by the Ministry of Transport. The resulting document will be a map of the selected area with the identification of key elements, which will then be analyzed.
For the analysis of critical infrastructure elements, it is necessary to obtain background data from operators or owners of key elements (step 2). The underlying data will be represented by key technical and organizational data. As part of this step, a background data set for the analysis of key elements will be created, which will be the output document. This file is then handed over to the Ministry of Transport for further processing.

Subsequently, the Ministry of Transport will perform an analysis of the underlying data (step 3), in which it will compare the data with the set limit values of sectoral and cross-sectional criteria set by a government regulation [5].

The second phase is the evaluation, which is shown in red in the diagram. At this stage, it is first necessary to evaluate the revised sectoral criteria (step 4). Given that the sectoral criterion under the Government Decree [5] is exaggerated, it cannot include any element that could be identified as a critical infrastructure element in the road transport sub-sector. For this reason, the application of the sectoral criteria proposed in the framework of the "Summary of Infrastructure Quality and Resilience Assessment Methods" is recommended [12]. Based on the performed analysis, these criteria will then be evaluated in the next steps.

The evaluation of the sectoral criteria reveals the need to decide whether the element meets at least one of these criteria (step 5). If the assessed element does not meet any of the sectoral criteria, it can be stated that it is not an element of critical infrastructure and this step ends the assessment process. If it meets at least one of the sectoral criteria, the process proceeds to evaluate the cross-cutting criteria.

Consequently, it is necessary to evaluate the cross-cutting criteria, which are the same for all economic sectors and are assessed according to government regulation [5] from three points of view: the number of victims, the economic impact and the impact on the public. For each aspect, a limit value is determined to determine.

After evaluating and assessing the cross-sectional criteria, it is necessary to decide whether the assessed element meets at least one of the cross-sectional criteria. If the assessed element does not meet any of the cross-cutting criteria, it is not considered as a critical infrastructure element and the process ends in this step. If the selected element meets at least one of the cross-sectional criteria, it fulfills all the conditions necessary for the identification of critical infrastructure elements.

The third phase of the process focuses on identifying critical infrastructure elements at the national level. Once the assessed element has met the assumption of a sectoral and cross-cutting criterion and thus becomes an element of critical infrastructure at the national level, it is necessary to decide whether or not it is an organizational unit of the state. This will affect the further determination process.

If it is not an organizational unit of the state, the Ministry of Transport, as the competent administrative body, shall issue the document Measures of a General Nature. This document will set out the elements of critical infrastructure in the national transport sector. The Ministry of Transport must immediately inform the Ministry of the Interior about this step of determining the elements of critical infrastructure and the subsequent issuance of Measures of a General Nature. By transmitting the information to the Ministry of the Interior, the element is designated as an element of road critical infrastructure.

If the operator or owner of the assessed element is an organizational unit of the state, the Ministry of Transport shall submit to the Ministry of the Interior a proposal for inclusion of the assessed element of road transport in the list, which will be the basis for determining critical infrastructure elements.

This list of elements will be submitted by the Ministry of the Interior to the state government, which will approve it and decide on the acceptance of the proposal. If the state government accepts the proposal, it will issue a government resolution as an output document, which will contain a list of designated elements of the national critical infrastructure. With this step, the selected element is determined as an element of road critical infrastructure on the territory of the state, i.e. at the national level.

In the last phase of the process, marked in orange, it is necessary to find out whether it is an element of European critical infrastructure or not. The aim of this step is to evaluate the conditions for designation as an element of European Critical Infrastructure under the Council Directive [12], which is carried out by the Ministry of Transport in cooperation with the Member States concerned. The designation of an element under consideration as a critical infrastructure element requires the consent of all Member States concerned by the element. The specific procedure for assessing the criteria is set out in four successive steps in Annex III of the Council Directive [12].

On the basis of an evaluation of the steps for identifying elements of European Critical Infrastructure, it will be further decided whether or not it is an element of European Critical Infrastructure. If the element under assessment fulfills all four steps set out in the Council Directive [12], it will be proposed for designation as a European Critical Infrastructure element by the European Commission, submitted by the Ministry of the Interior, and this step will complete the identification process. If the selected element does not meet the criteria for designation as a European Critical Infrastructure Element, it will remain a critical infrastructure element at the national level. This step completes the process of identifying critical infrastructure elements.

6. Conclusion

Securing the functioning of critical infrastructure aims to alleviate the problems associated with the failure of its elements. In order for critical infrastructure elements to be protected, they must first be properly identified. Given that there are different requirements and criteria for each sector of the economy, the different procedures for identifying critical infrastructure elements need to be addressed separately.

A total of five entities (owner or operator of the element, Ministry of Transport, Ministry of the Interior, state
government, and European Commission) are involved in the process of determining critical infrastructure elements. At present, entities at the regional level are not involved in the identification process, but only at the national or European level.

The proposed process for identifying critical infrastructure elements has been divided into four phases, namely preparation, evaluation, identification of national critical infrastructure elements, and identification of European Critical Infrastructure elements. The scheme was created using the decision-making process and the involvement of entities and output documents, along with an indication of the interrelationships between them. The design scheme of the process of determining critical infrastructure elements will facilitate orientation in this issue and thus enable better identification and labeling of selected elements as critical infrastructure elements.

Acknowledgments

This research was based on the support of the Internal Grant Agency of Tomas Bata University in Zlín, the IGA / FAI / 2020/003 project and the Institute of Safety Engineering, Faculty of Applied Informatics.

References

Study of Problems Faced when Establishing Military Field Camps

A. Krivcovas¹, N. Dobrzinskij²

¹The General Jonas Žemaitis Military Academy of Lithuania, Silo g. 5A, LT-10322 Vilnius, E-mail: andrejus.krivcovas@lka.lt
²The General Jonas Žemaitis Military Academy of Lithuania, Silo g. 5A, LT-10322 Vilnius, E-mail: nikolai.dobrzinskij@lka.lt

Abstract

The following article analyses the theoretical aspects of a military field camp by defining the concept of a field camp and meaning thereof, by discussing its application in the army, and offering research methodologies for solving various issues and challenges under consideration. The second part of the paper presents a unit in which the selected researches were performed. The detailed course of research while using three different methods is presented, namely that of the analysis of the target group survey, in-depth interview and comparative analysis. The analysis of the target group survey provided data on the establishment of a military field camp, indicated things that are necessary when establishing a field camp and showed what problems are most often encountered by said camps. Four respondents holding different military positions, involved in the process of establishing a field camp, were interviewed using the in-depth interview method. This research sought to identify issues and challenges faced during the establishment of a field camp and the process of planning. The method of comparative analysis was used to identify the disadvantages and advantages of setting up a military field camp, based on camp plans, NATO standards and hygiene rules. This method additionally seeks to identify the causes of problems found by the research methods employed previously. The operational process method will be used to depict diagrams that show the improvement of the establishment of a military field camp after solving the problems. The method of root cause analysis will identify the problems that belong to the appropriate groups.

KEY WORDS: military field camp, camp standards, establishment of a camp

1. Introduction

Military field camp is a territorial area where military and civilian personnel reside and work. Such military camp must be equipped with all the necessary equipment and materials to enable soldiers to plan operations, live and have a rest. In a military field camp, various hired civilian companies perform the functions assigned to them while improving the infrastructure of the camp and the quality of life of people residing there. The staff working in a military camp perform important functions. It always depends on the personnel if the deficiencies in the camp are rectified quickly or pile one on top of the other resulting in an ever growing problem for everyone. In order to minimize the number of possible future problems when establishing a camp, it is necessary to decide what type of personnel to hire. Field camps are divided into three types, namely:

- Patrol base, which is a military field camp active for up to 30 days;
- Operating camp, which is a military field camp active for up to 180 days;
- Long-term camp, which is a camp where battalion-sized subunits settle down. A military camp is built when it is (to be) inhabited for more than 180 days.

A military field camp has a logistical function to perform. In other words it is a place where various supplies, such as food, water, ammunition, medical supplies, and so on, are continuously used and stored. The size of the field camp to be set up depends on the type (number of soldiers and duties performed) of the military subunit that will reside there. The number of inhabited tents depends on the size of the camp, and the amount and type of the equipment to be transported and stored depend on the purpose of the subunit [1]

Relevance of the article. The establishment plan and the performance and functioning of the military field camp are very important when performing a military unit operation. Every army of a NATO country strives to set up a military camp that is as flexible and comfortable as possible. NATO has set standards for the establishment of a military field camp, and each country belonging to the organization relies on this standard. Location, weather as well as seasons all determine the specifics of the utilities of a camp, and the establishment of camp facilities and premises, the selection of their location is very important for the quality of all activities and operations performed in the camp area.

Objective of the research paper: to provide solutions for improving the establishment of a military field camp.

Tasks set for the research paper:
1. To perform the analysis of the situation of establishment of military field camps by using the selected methods.
2. To identify problems faced when establishing military field camps.

This article deals with the analysis of three groups: working methods, resources, and human factors. The problems belonging to these 3 groups are examined here, whereas obtained conclusions contribute to solving the
problems identified.

2. Research Methodology

By applying research methods, the objective is reached and the relevant problems are revealed. Following selection of the methods of analysis and completion of studies, problems are clearly identified [2]. Upon identifying the problems solutions are being sought, on the basis of which the military field camps, their infrastructure, utilities, machinery and even their establishment itself will be improved.

The research methodology was employed during the comparative analysis as an additional tool to identify the problems. In order to identify the main problems that the soldiers face when providing services to the field camps, a questionnaire was prepared. The survey involved 11 out of 12 professionals who serve in the field of outdoor services (hereinafter LPK) and are constantly exposed to service provision-related processes. The questionnaire consisted of 12 questions related to problem identification and 4 questions about the respondent. The questions were dichotomous, open and closed. Using the Paniotto formula to calculate the minimum sample size with a margin of error of 0.07, the minimum number of respondents was found to be 11. This means that the reliability of the data provided is over 93%. Composition of the surveyed group: people of different rank categories and ages that received different education and have worked in the Lithuanian Armed Forces for different periods of time (for at least 4 years) and thus have a different experience when it comes to the establishment of a military field camp; it can be stated that the interviewed soldiers are specialists.

3. Use of the Utilities at a Military Field Camp

Each year logistics is improving both in civilian companies and in the army. A special role in modern logistics is played by effective decisions made by the person responsible for the logistical functions of his activities. Effective decisions are made individually and in groups, using a variety of logistical analysis functions. In military field camps, in order for various equipment to be used properly and economically, without wasting resources, the actions and decisions that the equipment exploitation planner will make must be properly considered [3]. Logistics management must ensure constant control of the economy, that is, to compare price and quality. Upon comparing price and quality, it is necessary to assess whether it is worthwhile to use or exploit that equipment [4]. In order to start the performance of the equipment and to avoid losses, direct and alternative routes, as well as vehicles with which the equipment will be transported, must be thoroughly prepared and considered. Alternative routes need to be envisaged to enable the military personnel to take them when stuck in traffic jams or when the main road is selected for road works. These things need to be assessed in advance in order to avoid economic losses [5]. Equipment to be used is transported to a military field camp by trucks, trailers, or semi-trailers. Such equipment must be transported carefully to prevent any damage or injuries, so it is secured with special straps and, in order to prevent any damages when unloading or loading the vehicle in which it is transported, it is loaded with a special lifting device. In military units, the transporting of equipment is usually performed by military machines such as SISU E13TP. A SISU vehicle carries equipment mounted on a trailer or carries a container mounted with the necessary equipment inside of it [6]. Equipment that is transported mounted inside of containers or on truck trailers usually includes refrigerators, toilets, tents, showers, a wash room, armoured cars and large water tanks. When it comes to transporting a load, the subunit must suffer as little loss as possible, which means that the truck must travel a mileage that does not exceed the calculated fuel consumption and move at the appropriate speed [7]. Equipment which is loaded onto a truck trailer must be secured in such a way that the driver does not have to stop the vehicle in certain parking areas in order to correct and adjust the position of the load by securing it again and again. Extra stops use extra time and cause extra fuel consumption as the vehicle decelerates and stops, and when it starts moving again, it needs to regain the right speed, and when gaining speed with extra load, the fuel consumption increases. There are European Union road standards, which indicate the speed at which vehicles of a given mass are allowed to move when travelling with or without loads. These standards are intended to ensure safety of drivers and to prevent damage to equipment being used [8]. Containers are designed not only for transportation of equipment but also for storage of drinking water or fuel. The containers are equipped with large-capacity tanks for transporting drinking water, washing water, vehicle cleaning water and fuel. As water is one of the main sources necessary to keep soldiers alive, it is brought to a military field camp on a regular basis, so it is necessary to calculate how many large tanks will have to be transported to a military field camp consuming as little fuel as possible. Water and food are the main resources that any soldier needs, so the focus is primarily on their use. Fuel consumption needs to be calculated not only for the transportation of water or fuel to the camp but also for the arrival and departure of various items. Rubbish is one of those items that needs to be removed from the camp on a regular basis [9]. Rubbish is not to be stored in a military field camp. In accordance with the hygiene rules of military field camps, non-food waste is taken from the camp to a landfill, but in the absence of such a possibility, with the permission of the environmental authorities, this kind of rubbish may be burned at a specific place marked with special signs. Food waste is transported by the vehicles of the subunit to the nearest unit, where they are disposed of. If this is not possible, a pit of at least 2.5 meters is dug at a certain location in the camp, into which food waste is then loaded. When this pit is filled with food waste and 0.9–1 meter remain at the top, it is buried and that place is marked, then a new pit is dug next to it at a distance of 0.5 meters. These pits are excavated about 20 meters from the dish washing facility [7].

Each military field camp has personnel from various civilian companies as well as military personnel, each of
whom performs certain functions and the necessary jobs assigned to them. In order to select a suitable civilian company that does not significantly worsen the economic situation of the client, certain criteria must be taken into account, i.e., it is necessary to compare several companies and look at their market position and the efficiency of their employees, as well as the quality of their work and the time that it takes for them to perform it. After comparing and evaluating these criteria, a more suitable company is then chosen [10]. A military camp must always have its own protection. This function is performed by the soldiers residing in it. Military personnel go on duty and are on call for a set period of time, and, after performing their duties, rest for a set period of time. Their function is to protect the camp from various dangers that threaten it and to warn all military and civilian personnel residing there as soon as possible of the impending danger [11].

In summary, it can be stated that the personnel of civilian companies work and build premises, buildings and barriers differently than military units do, but in Lithuania, unlike in foreign countries, everything is normally done by soldiers themselves. Only those civil companies that supply soldiers with food, install toilets, maintain and clean buildings, and supply tables, chairs and other equipment to the canteen premises are hired. Military personnel in Lithuania usually both set up the camp themselves and perform most of the functions in it.

4. Identification of Issues and Challenges Related to Establishment of a Military Field Camp

The camp, the plan of which is comparatively analysed below, was built for the purpose of practical training. It was built by 300 soldiers in accordance with the Tier 2 of NATO STANAG standards. As mentioned before, NATO STANAG standards can, but do not absolutely have to be, relied upon, but failure to do so can lead to problems that arise during the period of the establishment or after the field camp has already been set up. When problems arise, various additional resources need to be used. It is necessary, though, to follow the rules of hygiene, which specify certain distances in order to avoid various diseases or inconveniences in the camp.

Plans for military field camp are prepared by the subunit that orders the military field camp. Once the plan has been drawn up, it is sent to the commander, who decides whether to approve the plan or not. After the process of the approval of the field camp plan is initiated, the specialists responsible for the establishment of the field camp get acquainted with the plan and start carrying out reconnaissance, that is, an insight into the area where the field camp will be set up. The location of each infrastructure of the military field camp is inspected. After the reconnaissance, the plan of the field camp used for the establishment of the military field camp can be modified but only to a minimum extent.

In Lithuania, military field camps are usually built in a training area, therefore no protective walls, fences, security posts, security towers and passing points are built within them. These security systems are not built due to the reason that the established perimeter of the training area is already guarded by the Lithuanian Armed Forces, therefore it does not make sense to build additional security measures in the military field camp, which is being built within the territory of the training area. The military field camp that is being built in is not within the territory of the training area, but it is in the territory of the Republic of Lithuania, and Lithuania is currently at peace, so it is not necessary to set up a service that will patrol around the perimeter and protect the area from outsiders.

Upon comparing the plan of the military field camp, which was developed before the establishment of the field camp, and the one which was prepared three days after the establishment of the military field camp, it can be stated that the plan, which was drawn up before the establishment, lacks a large amount of infrastructure and has some other changes. The analysis of the target group survey shows what caused the plan to be changed after starting to establish the military field camp. One of the reasons is the cooperation between the logistics battalion and other subunits that have ordered the establishment of the military field camp. Cooperation is one of the most important things, because it can lead to unanimous solutions and help avoid most losses. Reconnaissance is the exploration of the territory and collection of information. Upon completion of the reconnaissance, soldiers can introduce slight changes to the plan of the military field camp and prepare transport, equipment, and various material items. When changing some details of the plan, no cooperation between the subunits takes place, which leads to shortcomings in the establishment of the military field camp and additional requests from the client to improve said camp.

Lack of human resources is another existing problem that did not allow for the field camp to be fully equipped during the process of setting it up. The lack of certain specialists and the ordering of their services during the process of setting up the camp consumed time resources, which is why some elements of the infrastructure were not installed in time.

It is not mandatory to rely on NATO standards, but it is recommended to do so. Consequently, there are rooms in the camp that do not meet NATO standards and take up more space in the camping area than they should. In this case, we are talking about living quarters (tents). The tents do not meet NATO STANAG standards for an area prepared to accommodate 10 people. Currently, one tent can accommodate 5–6 soldiers equipped with a military bed and equipment, so in order to accommodate all soldiers, it is necessary to build more living quarters. More living premises will, of course, take up more space in the field camp. When installing additional rooms in a military field camp, the distance that must be kept between the rooms, as specified in the rules of hygiene standards, is sometimes not calculated. During or after the establishment of a field camp, it is often necessary to adjust its plan, put additional work in it and refurbish certain premises, which is why additional resources are often used.

The diagram below (see Fig. 1) shows the establishment of a military field camp and its preparation for the functions it shall perform. The diagram depicts the works from the beginning of the planning to the settling down of the subunit in the military field camp and the completion of the elimination of deficiencies. The occurrence of deficiencies
is one of the problems that might come up after the subunit settles down in a military field camp. Said deficiencies occur due to poor communication with another subunit.

Fig. 1 Diagram depicting the process of setting up a military field camp

The diagram below (see Fig. 2) shows the establishment of a military field camp after the plan has been drawn up, from the completion of the reconnaissance to the end of the setting up of the military field camp. The process of setting up a military field camp is the responsibility of two subunits and one person, i.e., the entity ordering the military field camp (the subunit that orders the field camp according to the plan that it has drawn up) and the commander of the unit ordering the military field camp, who approves the plan drawn up by the subunit and sends it to the developer. If the plan is not approved by the client, it is reviewed and improved. The improved plan is sent back to the client and if the plan is approved, the client writes a list of the material items and services needed at the military field camp. He then sends this list to the head of the military camp, who confirms the material items in possession and those that are available, and the services that they can provide. If the developer is unable to provide certain material items or services, they provide a list indicating those things and services. The client then takes care of material items and services and acquire them from his battalion or brigade. After the approval of the material items and services, the developer begins to analyse the plan and think about the establishment of a military field camp. It all starts with carrying out a reconnaissance, that is, exploring the area and selecting the location of the infrastructure. After the reconnaissance is completed and if the site complies with the plan, the plan is approved and further actions begin. If the plan does not conform to the location, however, it is corrected to meet the requirements of hygiene standards and the site. After the approval of the final plan, the process of preparation of material items, vehicles and special equipment, and ordering of various services starts. Said jobs are performed simultaneously and after their completion, the entire infrastructure is transported to the site of the field camp. Upon reaching the site where the field camp is to be established, the setting up of a military field camp begins. After establishing a field camp, the settling down of the subunit takes place in it. When a subunit settles down in a field camp, problems such as equipment failure or the need for certain pieces of equipment or infrastructure from the ordering subunit usually occur. All these problems could be avoided by means of cooperation between the subunits during the establishment of a field camp. In the event of various deficiencies, additional resources (fuel, time, human, financial) are used. If said deficiencies are not eliminated within one day, they are tried to be remedied until all parts of the infrastructure are perfectly operational. After eliminating the deficiencies in the camp, the establishment of the camp is finally thought to be completed.

Fig. 2 Diagram depicting the process of establishing a military field camp
The jobs specified in Diagram 2, for which a particular subunit is responsible, are performed by the subunit before or during the establishment of the camp. Different jobs are given time within which the subunits need to complete them. If the subunit performs its assigned activity poorly, it needs to be further analysed, corrected and redone, which takes up quite a lot of time, and time is important because additional work, such as repairing equipment, parts of infrastructure or upgrading a field camp, requires soldiers to work more and for a longer period of time. It results in extreme tiredness of soldiers as well as additional financial costs.

The diagram in Table 1 describes the issues and challenges faced when regarding setting up a military field camp. These are assigned to certain groups that they belong to such as working methods, non-compliance with NATO standards of military field camps, resources and human factors. These groups cover certain problems that were revealed during the research.

<table>
<thead>
<tr>
<th>Working methods</th>
<th>Non-compliance with NATO standards in military field camps</th>
<th>Resources</th>
<th>Human factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Changing the plan of a military field camp.</td>
<td>1. Establishment of facilities for accommodation in accordance with the requirements of NATO standards; 2. Lack of leisure facilities in a military field camp; 3. Non-compliance of infrastructure installation distance with NATO standards.</td>
<td>1. Insufficient equipment; 2. Insufficient human resources to set up a field camp; 3. Insufficient transport and lack of specialists.</td>
<td>1. No inspection of equipment prior to the establishment of a military field camp; 2. Non-compliance with the established military field camp plan; 3. Failure to carry out the establishment of a military field camp on a constant basis.</td>
</tr>
</tbody>
</table>

The group of Working Methods includes the following two main problems: changing the plan of the military field camp and the lack of cooperation between the subunits. The resources group includes the following four problems: insufficient equipment; insufficient human resources to set up a field camp; insufficient transport and lack of specialists. The group of Human Factors includes the following three problems: no inspection of equipment prior to the establishment of a military field camp, non-compliance with the established military field camp plan, and failure to carry out the establishment of a military field camp on a constant basis. The group of Non-Compliance with NATO Standards in Military Field Camps includes the following three problems: establishment of facilities for accommodation in accordance with the requirements of NATO standards, lack of leisure facilities in a military field camp and non-compliance of infrastructure installation distance with NATO standards.

5. Conclusions

An analysis of scientific literature leads to the conclusion that weather conditions, location and size of future field camp must be taken into account when setting it up. The amount of equipment transported to the site of a military field camp is highly dependent on the size of the camp. There are three types of field camps: patrol base, operating camp and a long-term camp. Each of the field camps has their size and appropriate infrastructure. The time that it takes to set up a military field camp depends on weather conditions and location. Special equipment tidies up the area where the military field camp is to be located and slows down the process of setting up the military field camp. NATO standards and hygiene regulations must be taken into account when setting up a field camp. The exploitation of the equipment requires resources that need to be allocated appropriately so that the established norms are not exceeded. An analysis of scientific literature suggests that with sufficient resources, equipment, vehicles and the application of NATO military field camp standards, it is possible to set up a military field camp without any deficiencies.

Upon assessing the functions of the establishment of military field camps of various tiers of NATO standards, it can be stated that in the military field camp each premise has a certain space where it has to be established. The specific site is chosen by the person planning the construction of the military field camp and is based on NATO standards. Each facility assigned to a particular tier must meet NATO standards. Each tier indicates the relevant premises, and the necessary number of them. The size of a military field camp and the period of its existence depends on which tier it is assigned to. Therefore, when setting up a military field camp, it is necessary to take into account its size and decide what premises should be installed there.

In a result of selecting the methods for analysis and performing the analysis of the situation of the establishment of the military field camp, it can be stated that most of the problems regarding the establishment of the military field camp occur due to failure or insufficient quantity of various types of equipment, or lack of resources. The process of setting up a field camp starts with drawing up of its plan and continues with the partial settling down of the unit that ordered the camp. In order for a military field camp to be set up efficiently and quickly, the existing shortcomings must be remedied.

After selecting the methods for analysis, the problems with setting up a military field camp were identified. Said
problems stem from a lack of certain resources and cooperation, and non-compliance with NATO standards for establishing field camps. Resources are limited, so depleting all resources would be detrimental to soldiers stationed in a military field camp. When there is poor communication between the logistics battalion and the client, problems may occur when setting up a military field camp. Deficiencies in the field camp and the presence of soldiers from the ordering battalion result in a delay in the planning and execution of various tasks.

Appropriate solutions need to be put forward to address the problems with setting up a military field camp. The following proposals solve the issues regarding plan change and cooperation: discussions between the two subunits must arise when drawing up and adjusting the plan for a military field camp. Both subunits have to conduct discussions regarding military field camp plan and carry out the reconnaissance process together. Deficiencies in equipment will be remedied if the equipment is constantly inspected, and the establishment of a military field camp will proceed in a consistent manner if each soldier is trained to work and repair the equipment assigned to him. The efficiency of the process of setting up a military field camp is reduced due to a lack of resources. The problem of the lack of professionals and vehicles can be solved in the following ways: by repairing existing damaged vehicles, renting trucks of civilian companies, encouraging and allowing soldiers to serve in the logistics battalion, and sending existing soldiers to specialist courses. Solving these problems makes the establishment of a military field camp more efficient, faster and requiring less resources.

References

Maritime Security: Piracy & Terrorism at Sea

A. Galieriková¹, A. Dávid², J. Sosedová³

¹University of Žilina, Univerzitná 8251/1, 010 26 Žilina, Slovakia, E-mail: galierikova@fpeds.uniza.sk
²University of Žilina, Univerzitná 8251/1, 010 26 Žilina, Slovakia, E-mail: andrej.david@fpeds.uniza.sk
³University of Žilina, Univerzitná 8251/1, 010 26 Žilina, Slovakia, E-mail: sosedova@fpeds.uniza.sk

Abstract

A threat of terrorism in general has increased in recent years, mainly since the terrorist attack against the US on September 11th, 2001. This terrorist attack has started a new period of history. The period, that can be characterized as unstable and unpredictable, and bringing a lot of changes, mainly in the field of increasing safety & security. The primary output of the paper is the comprehensive analysis and comparison of the most serious types of unlawful acts (piracy and terrorism) taking into consideration the legislative and jurisdiction.

The main objective of the paper is to investigate the current state of unlawful acts in maritime transportation. The analysis consists of the description of the most vulnerable shipping routes and areas, frequently by maritime criminals.

The paper also briefly examines the potential consequences of unlawful behavior at sea and possible counter-measures against such actions.

KEY WORDS: maritime security, unlawful acts, piracy, terrorism

1. Introduction

Maritime transportation is essential to the world’s economy as over 90% of the world’s trade is nowadays carried by sea (Galieriková, 2020) [1]. This type of transportation is, by far, the most cost-effective way to move en masse goods and raw materials around the world. As the maritime sphere is an unregulated area, both the crew and ships are vulnerable to violence at sea. Terrorists and pirates, operating in the marine domain, also can affect international trade. Motive designates whether an incident will be classified as an act of terrorism or the act of piracy. Pirates and terrorists rarely cooperate in executing of maritime attacks, because the motive of these groups differs. While pirates only see a financial or material gain with minimum violence used, terrorists, on the other hand, are driven by the political, religious, or cultural purposes to destroy world sea trade. In comparing maritime piracy and terrorism, several other factors (use of violence, strategies, etc.) will be examined. According to Joubert (2013), in the host countries, the incorrect setting of socio-economic and political principles is the main contribution to the existence of maritime violence [2].

Terrorism is considered as the worst type of unlawful act. After the terrorist attacks on the US on 11th September 2001, maritime terrorism and piracy were increasingly connected and became a highly controversial issue. Nowadays, a new threat is emerging - terrorists use a vessel carrying dangerous goods (mostly tankers or vessels carrying dry dangerous goods) as a weapon. To convict sea violators, it is necessary to identify different attacks on the sea and classify them into a correct category (piracy, acts of armed robbery and terrorism), to know the maritime legal environment and also to recognize different maritime zones, that has great importance for the exercise of jurisdiction.

2. Legislation, Jurisdictions and Definitions

Generally, many conventions and treaties are applied in relation to the sea. The United Nations Convention on the Law of the Sea – UNCLOS (1982), is considered to be the principal statement of the rules governing general relationships and jurisdictions at sea. UNCLOS (1982) establishes maritime zones that characterize the delimitation of the seas: archipelagic waters, territorial sea, internal waters, contiguous zone, exclusive economic zone, continental shelf and extended continental shelf, high seas and the deep seabed [3]. The convention also establishes the baseline, as a tool “measuring the breadth of the territorial sea is the low-water line along the coast as marked on large-scale charts officially recognized by the coastal State”. The maritime zone has a major impact on whether an unlawful act will be qualified under international law (if it takes place on the high seas); under the national law of the coastal State (if the attack takes place in the territorial sea) or under national law (if carried out on the high seas). The marine zones defined in UNCLOS (1982) (Fig. 1) have given rise to the form of many different definitions of unlawful acts at sea. Both the International Maritime Organization (IMO) – as a specialized agency of the United Nations (UN)’s, and the International Maritime Bureau (IMB) currently use the definition of piracy as described in the United Nations Convention on the Law of the Sea.

So, UNCLOS (1982) defines piracy as:

a) any illegal violent act, or any act of depredation, committed for private purposes by the crew or the passengers of a private ship or an aircraft, and directed:
i. on the high seas, against another ship or aircraft, or against persons or property on board such ship or aircraft;

ii. against a ship, aircraft, persons or property in a place outside the jurisdiction of any State.

b) Piracy is also defined as any act of voluntary participation in the operation of a ship or of an aircraft with knowledge of facts making it a pirate ship or aircraft.

Fig. 1 Maritime zones and its sovereignty (UNCLOS)

UNCLOS (1982) also defines piracy as any act of inciting or of intentionally facilitating an act described in paragraphs a) or b) [3]. This definition limited piracy as acts outside the jurisdiction of the territorial sea of a state. Unlawful acts committed in the territorial sea are considered to be an armed robbery. Thus, many violent acts occurring in 12 nautical miles (NM) from the baseline are excluded from the piracy definition. Maritime terrorism is also excluded because political motives are not included in that definition.

IMO Resolution A 1025 (2010) has defined armed robbery against ships as any of the following acts:

- any illegal act of violence or detention or any act of depredation, or threat thereof, other than an act of piracy, committed for private ends and directed against a ship or against persons or property on board such a ship, within a State’s internal waters, archipelagic waters and territorial sea;
- any act of inciting or of intentionally facilitating an act described above [4].

The act of maritime terrorism still does not have any valid definition. Nowadays, an agreement is adopted to use the operational definition, under the 1988 Convention for the Suppression of Unlawful Acts for the Safety of Maritime Navigation. But still, this convention does not appoint to terrorism specifically. So, maritime terrorism is defined as any attempt or threat to seize control of a vessel to:

- damage or destroy a vessel or its cargo;
- injure or kill a person on board a vessel;
- to endanger the safe navigation of the vessel that moves from the territorial waters of one State into those of another State or international waters.

There are more differences than similarities between piracy and terrorism at sea. The main cause is that the tactics and objectives of the attackers differ. The main reason why to recognize the main differences between piracy and terrorism is to establish effective policies and counter-actions. Probably the most noticeable difference between pirates and terrorists is the motive. Pirates, driven by the financial motives, are satisfied with stolen money or cargo, and when they get what they want, they usually release the ship and the crew. On the other side, terrorists, often using violence to achieve their goal, which is often to jeopardize world maritime trade for political, cultural, religious or purposes. Another distinction is that pirates use only uncomplicated tactics, while terrorists use refined and precise strategies. Piracy also operates mainly at the local level, while terrorists can have a more global reach (because of their objectives). According to Chew (2010), there are also terrorist groups operating only at the regional level with the main objective of accomplishing political agendas at such level (groups LTTE, Gerakan Aceh Merdeka, ASG) [5]. Another difference is that pirates try to operate as “invisible”, avoiding the attention, while terrorists seek it to promote their purpose.

In addition to the obvious similarities between piracy and terrorism in the form of excellent maneuvering skills, there are other significant similarities. Fast boats smaller dimensions are often chosen for both groups’ operations (effectiveness to evade radar detection, better maneuverability, and less expensive maintenance). Both, pirates and terrorists need a shore station from which they operate. Actions of both groups are planned rather than impulsive, mainly aimed at civilians. According to Frécon (2008), legal and jurisdictional weaknesses of several attacked countries, geography, inadequate security or under-funded law enforcement, favor both maritime pirates and terrorists, create a proper environment where unlawful acts can flourish [6]. The main hole in the system is represented by venal, corrupted government, mainly in areas where Somali pirates operate - areas of the Kenya territorial waters and east of the Somali coast, and the area of Gulf of Aden.
The geography is another significant factor influencing on maritime terrorism, mainly in Southeast Asia. Narrow channels, slowing down the traffic, together with thousands of islands, providing shelter are all to the advantage of maritime attackers. Overlapping jurisdictions of coastal countries (of their territorial seas) represents another problem for law-enforcing agencies.

3. The Most Distressed Areas

According to David (2019), most of the goods produced in Asia are transported to Europe by seagoing ships along the old trade route through the North Pacific Ocean, South China Sea, Strait of Malacca, Indian Ocean, Bab-el-Mandeb Strait, Suez Canal, Mediterranean Sea and North Atlantic [7]. However, this transport route has several disadvantages, such as high channel charges across the Suez Canal, delays in navigating the Suez Canal, but especially piracy in the Gulf of Aden or the Straits of Malacca.

3.1. Strait of Malacca

The Straits of Malacca is located in Southeast Asia between the Malay Peninsula and the island of Sumatra. Due to its geographical location (between the Indian Ocean and the Asian continent), it ranks among the world's most important sea routes. Sustainability of transport security across the Straits of Malacca thus becomes a key element for local, regional and international actors. Qu (2012) claims that up to 40% of world trade is transported through the Straits of Malacca, represented by 70,000 ships per year [8].

Piracy, armed robberies, and terrorism are the main threats in this area. Because UNCLOS (1982) defines piracy as unlawful acts of violence or detention executed on a vessel in the area of the high seas or in an aircraft in the area not under the jurisdiction of any state, armed attacks (robberies) in this area are not perceived as piracy [3]. It is therefore very difficult to work together to deal with the consequences of the attacks in the Straits of Malacca. There is a paradox that ships crossing the Straits of Malaysia cannot defend themselves sufficiently without the help of neighboring states.

According to Hanšút (2017), the ransom demanded by pirates is paid by the state in whose territorial seas the attack took place [9]. The ransom can also be paid by oil companies. The increase in oil prices around the world is a response to the armed attacks, which in more than 50% of cases are targeted at oil tankers. Raymond (2009) has identified several types of "piracy" in the Straits of Malacca - hijacking, armed robbery and hijacking for ransom [10]. Ship robberies take place mainly at night. These are mainly thefts of valuables from ship safes or thefts of navigation devices. Raymond (2009) argues that in these cases, the loot is worth up to $ 20,000 [10]. The hijacking of a ship due to transported cargo is much more complicated. Pirates must be able to handle maneuvers with the vessel, they must choose the "right" port where the discharge of stolen items will be ensured, and they must also provide facilities for storing stolen cargo before the sale itself. Raymond (2009) further argues that the ransom is then mostly used to buy weapons, and therefore paying the ransom to pirates de facto means supporting new attacks [10].

Another threat - terrorism is perceived as the worst type of illegal act. The aim of terrorist attacks is to disrupt world maritime trade by attacking cargo vessels on strategic maritime routes. According to Watkins (2004), the Straits of Malacca have often been threatened in the past by the organized terrorist group Al Qaeda, whose goal was to bring the speedboat close to naval merchant vessels and detonate charges remotely [11]. Vessels transporting chemicals and dangerous goods, together with vessels carrying valuable cargo were sought after by such terrorist groups.

Watkins (2004) claims that there are three Islamist separatist groups in the Straits of Malaysia - Gerakan Aceh Merdeka, Jema'ah Islamiyah and Abu [11]. The question remains whether terrorist groups would endanger Islamist countries that are dependent on oil trade. The disruption of maritime traffic in the Straits of Malaysia would have consequences for the whole world, including the states that Islamists consider to be their main enemies.

3.2. Gulf of Aden

The Gulf of Aden, located between Yemen and Somalia, is linking Mediterranean and the Arabian Seas. The gulf, on the edge of the Red Sea, is the only way ships can get to and from the Suez Canal, making it one of the busiest sea routes in the globally. According to Hanšút (2018) approximately 30,000 merchant ships pass through it each year, which poses a huge threat to international trade [9]. Today, Somali pirates are the most dangerous group of pirates. The origins of Somali piracy date back to the 1990s, when Asian and European private companies began to exploit anarchy and chaos in the country for illegal fishing and nuclear waste disposal. To protect their waters from illegal activities, Somalis set up the Somali Coastguard and National Volunteer Coastguards and divert suspicious ships from their waters. These groups became the basis of organized piracy. Unlike pirates operating in other parts of the world, they are mainly interested in hijacking ships and crew members. According to Závešický (2009), Somali pirates operate in two territories - the first is the high seas east of the Somali coast and in the adjacent waters of Kenya, the second is the Gulf of Aden [12]. The mainland bases for them were the town of Eyl in the province of Puntland and the town of Haradhere in the south of the country.

3.3. Gulf of Guinea

The Gulf of Guinea, is part of the Atlantic Ocean near the southwest Africa, is one of the largest bays in the
world with the total area about 1 500 000-kilometer square (Hanšút, 2018) [9]. Currently, the Gulf of Guinea represents the most dangerous maritime zone in the terms of the success rate of unlawful acts of violence.

The territorial seas together with the "EEZs" of Benin, Togo and Nigeria, are considered as the riskiest areas with various form of criminality, such as piracy, armed robbery, thefts, etc.). Somali pirates focus on capturing vessels, kidnap for ransom, and holding the crew members and shipment (mainly the high-valuable cargo) with the aim of extracting money from a ship-owner.

The attackers in this area also focusing on oil tankers transporting refined petroleum and vessels carrying chemicals. Hijackers are well coordinated, demonstrating great skills with operating these specialized ships, using the most accurate information about ship’s locations and the type of goods carried. According to estimation of Anyimadu (2013), 40% of Europe’s oil imports, and 30% of the United States’ imports of petroleum products, are transported through the Gulf of Guinea yearly [13]. So, this area represents the worst threat for the world seaborne trade with oil (Galieriková, 2020) [1].

3.4. The Caribbean Sea

This area is the part of Atlantic Ocean, lying southeast off the Gulf of Mexico, that ranges between coast of Central and South America. The Caribbean Sea, as one of the largest seas in the world (total area 2 754 000 km²) is important because of oil and natural gas extractions and, also, fishing. According to Hanšút (2018) millions of tourists come to the area every year for exotic holidays or cruises [9]. Even when the piracy currently reaches low level in the Caribbean region, it is not going to disappear. According to Hanšút (2018) present piracy in the Caribbean Sea is usually limited to attacks on small luxury boats, fishing boats and crafts [9]. But this can change quickly, and piracy can spread in this area, partly because of the disablement of host countries to guard their territorial waters sufficiently.

4. Statistics of Attacks at Sea

A comprehensive analysis of unlawful acts at sea in this section, stands on data collected from Annual Reports on Piracy and Armed Robbery Against Ships, prepared by the International Chamber of Commerce-International Maritime Bureau (ICC/IMB) [14]. The ICC/IMB Reports categorizes attacks in two sections – attempted and actual attacks. Actual attacks are the performed ones, resulting in the case of the hijacked or boarded ship under attack, while attempted attacks are unsuccessful – in this case, vessel was under attack (case of fired upon or an unsuccessful boarding). Fig. 2 shows both types of attack in the past 5 years.

![Fig. 2 Attempted and actual attacks at world seas, period: 2015 – 2019 (IMB)](image)

The IMB Piracy Reporting Centre has received 162 reports on piracy occurrence and armed robbery against vessels in 2019. In 2018, it was 201 cases of violence [14]. The 2019 numbers consist of 4 vessels hijacked, 17 attempted attacks, 130 cases of boarding and 11 cases fired upon. In 2019, 134 crew members were taken in 19 different cases from various vessels. The Gulf of Guinea accounts for over 90% of international crew members hijacking with yearly more than 50% growth (121 crew kidnapped in 2019 compared to 78 in 2018).

Fig. 3 represents unlawful acts at sea in period 2015 – 2019 overworld. In this period, the number of piracy attacks reached the highest point (245 cases of piracy in 2015).

The chart shows that the most distressed area is located in Southeast Asia. The number of incidents has significantly increased at Benin, mainly while anchoring the vessel. In 2018, (within several weeks!) 5 attacks were reported from this area. Next year, 35 crew members have been hijacked. Past several incidents show that violators operating in this location are well armed and extremely violent. In some of these reported incidents, several vessels have been fired upon. The pirates forced skippers and captains to sail their vessels to unknown areas where the vessel’s
properties and some part of the cargo was stolen. Crew members have also been injured.

![Fig. 3 Violent acts at world seas, period: 2015 – 2019 (IMB)](image)

In 2015, the amount of unlawful violent acts was of enormous 147. Fortunately, over the years, this number has been steadily declining, with the number of 53 unlawful acts in 2019. In the past, the incident occurred circa 170 NM from the Nigerian coast. In the past cases of violence against ships, pirates kidnapped ships for several days, ransacked them and stole cargo, mostly gas oil. Also, crew members were kidnapped and injured in these acts. Generally, all coastal and territorial waters of Nigeria remain dangerous. Ships are warned to be watchful, as many cases of violence may have gone unreported. Unlawful acts continue to rise extensively, especially the cases of hijacking crew for ransom.

4. The Situation in the First Quarter of 2020

The Gulf of Guinea stays one of the world’s piracy red spot with 17 crew members hijacked in 3 different cases, in the area between 45 to 75 NM from the baseline. IMB’s Piracy Reporting Centre (PRC) received 21 incident reports from the area of the Gulf of Guinea in the first quarter of 2020. 12 attacks were committed on ships in an area of 70 nautical miles off the coast [15]. Pirates, usually well-armed on their speedboats, sneak up onboard vessels, with the aim of stealing cargo and hijack crewmembers, expecting ransom.

In comparison to 2019, when 10 vessels were fired upon worldwide, four same incidents were already reported within Nigerian EEZ in the first quarter of 2020. Still, many attacks are unreported. The strategic disposition of Marine Police guard ships has led to a decrease in the numbers of attacks on ships in many Indonesian risky areas. In the Singapore Straits, five ships boarded were reported in the first quarter of 2020. These cases of armed robbery attacks are found as low-level attacks and are also considered as a distraction to crews navigating in congested waters [15].

Other cases of violence include the kidnapping of 5 crew members for ransom from January 2020 (attack on a fishing ship, Malaysia). In March, a guard was held temporarily by a group of robbers in Brazil [16]. At the same time, 3 crew members were held by 9 boarded robbers with the view to steal the vessel’s stores (Callao, Peru). During this incident, 2 crew were injured. Callao received another 5 attack reports in the last quarter of 2019 and 3 in the first quarter of 2020.

5. Conclusions

Piracy poses a huge threat to global sea trade, primarily in the Gulf of Aden, area off the Somalian coast, the southern Red Sea and the Arabian Sea, too. During the past 5 years, the number of incidents has decreased, mainly in the waters of the India Subcontinent and in south-east Asia waters. On the other hand, in the waters of west Africa and the Caribbean Sea, the number of violent attacks against vessels is still rising.

Although the number of maritime attacks has fallen to the lower level than ever before, due to attacks from the 11th of September in the USA and due to the increase of more sophisticated forms of terrorist acts, the fear that hijacked ship (mainly ships transporting dangerous goods) could be used as a weapon of mass destruction, still exists. The effect of such an act on the world trade, economy and environment could have catastrophic consequences.

As both pirates and terrorist eventually act in a host country, the political climate and socio-economic conditions in this country influence their operations. Unsteady legal framework and jurisdictional systems, together with a favorable political system in the host country will benefit both groups.

A significant output of this paper is a comparison of differences and similarities between piracy and terrorism. Although violent acts of sea pirates could impact the world trade, they usually operate only at a local scale, while many
terrorists and terrorist organizations globally operate on a global level. Another difference between pirates and terrorists is their objective.

Pirates’ interest is not to harm or kill, because of their fear of possible legal results of such an act. On the other hand, act like this means a lot of publicity for terrorists. Pirates are also worried about their own lives, while terrorists are not afraid at all - their attacks have often been suicide. Pirates almost never collaborate or cooperate with terrorists. The main similarity is using the same tactics for their different purposes. Hijacking, the most used tactic by both groups, is also the apple of discord during the exercise of jurisdiction, so it is difficult to be certain in this question.

According to Joubert (2013), attention should be paid to geographical areas and to deviations in pirate tactics to identify correctly any potential terrorist attacks to take counter-measures on time [3]. The most dangerous case is probably not the teamwork of pirates and terrorists, but a terrorist attack, wrong classified as a piracy act. The results, consequences, steps, and preventative measures took will differ considerably relating to these two situations.

References

8. Qu, X.; Menq, Q. 2012. The Economic Importance of the Straits of Malacca and Singapore: An Extreme Scenario Analysis, Department of Civil and Environmental Engineering National University of Singapore,
Assessment of the Economic Efficiency of Modernization of Railway Wagons

R. Zaripov¹, P. Gavrilovs²

¹Pavlodar State University, Faculty of Metallurgy, Machine Building and Transport, 140000, Pavlodar, Kazakhstan, E-mail: ramis.zaripov@mail.ru
²Riga Technical university, Institute of railway transport, Paula Valdena street 1, Riga LV-1048, Latvia, E-mail: pavel.gavrilovs@rtu.lv

Abstract

The article describes the methodology for calculating the economic efficiency of the modifications and upgrades of freight wagons. This process involves updating the fixed assets of the railway transport, equipping the existing rolling stock with modern equipment, using domestic and foreign innovative developments. The main components of the integral effect obtained during the modernization of the rolling stock of railways are described.

The economic evaluation of projects aimed at modernization using innovations must be carried out taking into account the mathematical model in the form of a problem of optimization of a linear function with restrictions.

The aim of the study is to develop the methodological foundations of the economic assessment of the modernization of freight wagons. Evaluation of economic efficiency is an important stage in the project to develop a complex of new generation freight wagons with improved technical and economic indicators, which the authors are engaged in.

KEY WORDS: modernization of wagons, economic effect, savings, implementation, discounted income

1. Introduction

Today, the issue of the development of railway transport is relevant, by increasing its innovative potential and susceptibility to technological innovations in general.

Michael Porter, a renowned American expert in the field of competition, noted in his monograph [1] that innovation and change play a major role in the competition. Increasing the competitiveness of an enterprise is possible only through the implementation of innovative projects in it.

The systemic, complex nature of innovation is reflected in the complexity and versatility of the concept of innovation. It includes a wide range of innovations with varying degrees of novelty embodied in their knowledge, used in various industries and fields of activity, implemented in various markets, etc. [2].

The problem of comparing the total costs of innovations and the results obtained from their use is currently relevant. It is believed that from an economic point of view, it is necessary to introduce only those innovations that provide an excess of the results obtained over the costs necessary to implement the innovations.

World experience shows that in countries with a well-thought-out and stably pursued investment and innovation policy based on research and development, the economy is developing at a high pace, and since rail transport currently occupies a leading position in the transport services market, the topic of evaluating an investment in it is most relevant.

Investments and innovations are economically related activities, since the introduction of innovations is impossible without investing money, and investments in the modernization of fixed assets without innovative developments are not effective. For example, the development of the economy of railway transport enterprises and JSC "KTZh" as a whole is not possible due to the reproduction of obsolete morally rolling stock. It is possible to consider in detail the innovations introduced into the design of the rolling stock of railways in the monograph [2].

The economic assessment of the implementation of the project for the modernization of rolling stock is carried out using the project's cash flows, which are determined in each separate billing period as the algebraic sum of cash receipts (inflows) to the company's settlement account and various kinds of cash expenses (outflows). At the same time, the cash flow characterizes the financial result of the company's activities for the billing period (most often a year) and is equal to the amount of funds remaining in the company's bank accounts after receiving profit and non-operating income, paying taxes, loans, depreciation, capital expenditures for investing in the company's activities.

2. Main Part

Assessment of inflows and outflows of funds, when introducing an investment project, is necessary to determine the main indicator of the effectiveness of an investment project - net present value (NPV), which in financial analysis and English literature is designated as NPV (Net Present Value) [3]. NPV is the accumulated discounted effect for the calculation period, reduced to the initial step at the discount rate, calculated by the formula:

$$NPV = \sum_{t=0}^{n} \left( P_t - 3_i \right) \cdot a,$$  (1)
where $P_i$ – the inflow of money in year $t$ is the cost estimate of the results, tig; $ \beta_j$ – money outflow in the year; $t$ – current and one-time costs associated with modernization, tig; $T$ – settlement period, years; $a$ – the reduction factor.

Today the rolling stock of the railway transport is morally obsolete and badly worn out, therefore its modernization is a necessary measure for JSC "KTZh". This process implies the renewal of fixed assets of railway transport, equipping the existing rolling stock with modern equipment, using Russian and foreign innovative developments.

The efficiency of rolling stock modernization is formed by reducing operating costs, as well as reducing road accidents by improving the safety systems of rolling stock.

When performing an economic assessment of projects aimed at modernization, using innovations, it is necessary to use a mathematical model in the form of a problem of optimization of a linear function with constraints. At the first stage of planning an investment project, it is necessary to estimate the total amount of Copt investment. The minimum possible amount of investments in an investment project (taking into account the specifics of railway transport, which requires reaching a certain level of traffic safety) can be calculated based on solving the problem of minimizing the target function

$$\sum_{i=1}^{n} K_i \rightarrow \min,$$

in the presence of restrictions on the reliability and economic efficiency of the project in the form

$$NPV = 0.$$

It is necessary to analyze investment projects using a multi-criteria approach that will help to make the right, and the only correct, investment decision [4]. The criteria can be both the already given criteria for maximizing net present value and minimizing project costs, and other criteria, for example, minimizing the project implementation period or maximizing the reliability of transportation (as an indicator of reliability, one can take the probability that the system will function correctly in the required conditions longer than a specified time)

$$K_{\text{reliability}} \rightarrow \max.$$

Note that the solution of multicriteria optimization problems leads to a set of “effective” solutions, each of which cannot be improved by one of the criteria. The choice of the optimal investment plan from the set of effective ones requires additional analysis of the importance of criteria, their possible values and, consequently, additional calculations. In this regard, when analyzing investments in innovative projects, it is preferable to use a mathematical model in the form of an optimization problem with constraints. Such problems are the maximization problem (1) and the minimization problem (2) with constraints (3) and (4).

When determining the NPV, it is necessary to assess the inflows and outflows of funds, when introducing an innovative investment project.

The decrease in the annual amount of operating costs due to the reduction in train travel time is determined by the formula:

$$\Delta C_{op} = e \cdot \sum N_i \cdot 365,$$

where $e$ – the cost of 1 train-hour; $\sum N_i$ – total reduction in train travel time per day.

The total reduction in train travel time per day will be:

$$\sum N_i = \Delta t \cdot N,$$

where $\Delta t$ is the reduction in travel time along the section.

The travel time along the section will be reduced by, which $\Delta t$ is calculated by the formula:

$$\Delta t = \frac{2L_p}{V_{w1}} - \frac{2L_p}{V_{w2}},$$

where $L_p$ – is the length of the section; $V_{w1-2}$ – local speed.

Expected annual savings in fuel and energy resources for train traction

$$C_{\text{oper,cons}} = C_{\text{el,con}} + C_{\text{diesel,fuel}}.$$
Expected annual cost savings associated with the wage bill for locomotive crews. Cost reduction under payroll for locomotive crews, per year is determined by the formula:

\[
\Delta P = \frac{\Delta N_p W}{12},
\]

where \(\Delta N_p\) change in the turnout number of locomotive crews; \(W\) – the average salary of a driver and an assistant driver per month.

The conditional economy of the locomotive fleet \(\Delta M_f\), is found by the expression:

\[
\Delta M_f = \frac{\sum N_t}{24},
\]

where \(\sum N_t\) – the total reduction in train travel time per day.

An additional effect was obtained from the acceleration of the innovation implementation phase. Determination of the additional effect obtained from the acceleration of the transition to the use of new technology [5]. It is necessary to take into account the effectiveness of increasing the mobility of production, when introducing innovation for mass application in the national economy, with additional consideration for accelerating the development of production, reducing the duration of the production cycle of products.

The current costs associated with the use of new equipment are most often taken in the amount of 5% to 25% of capital investments, when it is impossible to calculate the real costs.

Cash outflow from investing activities:

\[
C_{\text{inv}} = K_{cr} + K_{ras} + K_{frs},
\]

where \(K_{cr}\) – investment costs for the modernization of wagons and locomotives, circulating on closed routes; \(K_{ras}\) – investment costs for the modernization of rolling stock wagons; \(K_{frs}\) – investment costs for the modernization of wagons of the foreign rolling stock fleet.

It is rather difficult to assess the economic efficiency of introducing the result of research activities into practical application, especially in the railway industry. The overall effect is achieved through a certain set of criteria (Fig. 1).

![Fig. 1 General integral effect obtained during the modernization of rolling stock](image)

3. Conclusions

Analyzing the existing methods for assessing the economic efficiency of investment projects, one can draw certain conclusions. In particular, the implementation of investment projects aimed at modernizing the material and technical base of the industry is strategic, and they are innovative in their content.

A distinctive feature of innovation and investment projects is the presence of a high degree of uncertainty, which means that they are exposed to various kinds of risks. In this regard, there is a natural need for the economic evaluation of these projects to take into account all kinds of risks and assess the economic consequences of their manifestation. It is also proposed to take into account the effect obtained from the reduction of the implementation time of the innovative
project, which will be formed only as a result of accelerating the satisfaction of the economy's need for new transport services of improved quality compared to those previously used to perform the same functions, but obsolete.

The acceleration effect in this case is reduced to the modernization of the rolling stock, by replacing obsolete individual products and equipment in it with more advanced ones. At the same time, a direct result will be obtained from the introduction of innovation, which is due to the effect of replacing obsolete elements of rolling stock, equipment or technologies, which in general affects the economic efficiency of modernizing vehicles. And the savings in total costs in relation to the mass provision of transport services will generally reflect the effect of replacing the production cycle. In railway transport, various ways can be used to improve the efficiency of modernization of rolling stock and its elements designed to perform certain functions. Most often this is either an evolutionary development of technical means, or a qualitative leap in the development of technology.

References

Shape Harmonization of the Railway Track Transition Section & the Kinematics of Vehicle Body Design Point

G. Velichko

Credo-Dialog Company LLC, 5 Malyi lane, 220014, Minsk, Belarus, E-mail: vgvkurve@gmail.com

Abstract

This article considers the theoretical basis of quality assurance of vehicle’s turning motion over variable curvatures and body inclination. The necessity and possibility to implement new approaches to solving this problem are justified by the results of the research of functional properties of various shapes of track curves transition sections (hereinafter TS) with the aid of multifactor deterministic kinematic model (hereinafter MDKM), as described in [4]. Essentially this solution aims to harmonize nonidentical geometrical TS shape characteristics and the kinematics of the design point of the vehicle body by the criterion of formalized target function minimum. The effectiveness of the proposed approach was demonstrated by a comparison of the results obtained by applying the MDKM for evaluation of the quality of new and known shapes of TS. Results obtained in course of this research are useful for improving the functional quality of new or retrofitting existing track curves of ordinary, high-speed and super high-speed railway tracks, as well as for enhancing and perfecting standards and rules of their design.

KEY WORDS: railway transition section, transition curves, cant transition, vehicle body design point, harmonization

1. Introduction

Analysis of integral function performance characteristics for the railway track + vehicle system of different TS shapes shows that even the application of \( f(s) \) functions with high geometric quality which determines regularities of cant transition and the curvature, the result of force interactions between the elements of this system will not be satisfying and will not fulfill the requirements. To a large extent this is due to the empirical research character for earlier proposed TS shapes by means of probe and error, aggravated by:

- absence of formalized target function, with the aid of which this quality could be reached to a great extent;
- the inability to take all existing factors into account, which affects the possibility of reaching the desired target effectively;
- absence of a systematic approach in argumentation the necessary and sufficient properties of \( f(s) \) function characteristics which determine the TS shapes;
- stereotypical sameness of \( f(s) \) functions, which determine rail track axial curvature and cant transition;
- lack of complex feasibility of all geometrical characteristics of the TS, including its optimal length \( L \).

These demerits constituted the main premise to search for new TS shapes, which enable in the frame of the design parameters to reach the required performance of the railway track + vehicle system. Also, for the convenience of its construction and later maintenance only the classical style of the rail axis tracing at rail top level (hereinafter RTL) was considered. This allowed to preventively avoid problems consistent with the alternative “uplifted” style of tracing, described in [4].

2. Target Function Formalization

In terms of normal language, the aim of establishing and argumentation of new TS shape lays in: comfort assurance of passenger travel and positive dynamics of system components force interactions. But for measurable assessment of the desired requirements or coming close to accomplish them a quantitative criterion is needed, the kind that allows estimating the comfort level and its functioning quality for the railway track + vehicle system, valued by its ergonomic and technical aspect. It is concluded from the assessment of constructional and kinematic characteristics of this system, that for each of these aspects a smooth and gradual change of non-compensated lateral accelerations \( a(l) \) with minimal velocity \( v(p) \) are needed. For the technical aspect of this problem it is important to estimate these values at the design point of the vehicle center of gravity (hereinafter CG), and for the ergonomic aspect these measurements should be performed at the location level of the vestibular apparatus of the passenger.

For objective reasons the ideal regularities of integral indicators \( a(l) \) & \( v(p) \) could be reached only at one designed height \( H \), submitted in accordance to the priority of the performance aspect. Respectively, the corresponding \( a(l) \) graph should be of \( G^2 \) continuity with practically lineal shape throughout most of the TS length stretch. To such quasi-lineal \( a(l) \) graph corresponds \( G^2 \) continuity trapezium-shape of the graph \( v(p) \). At the same time, the horizontal line of its central part should be at maximal proximity to the line of minimal velocity level \( v_{\text{min}}(l) \), corresponding to the hypothetical lineal graph \( a(l) \) of the clothoid. Accordingly, the target function, which ensures the ergonomic aspect of quality at level \( H > CG \), can be graphically presented is its etalon graph shape derivative \( dv / dl \) (see Fig. 1).
By analyzing the obtained results with the help of MDKM in assessing different TS shapes, it was found that reaching the desired target by using its selfsame non-linear functions does not fulfill the purpose. Positive results were obtained only with non-linear cant transition $d(l)$ or with vehicle inclination slope $i(l)$, as well as angle tangent to TS axis $\beta(l)$. To describe them a subtype of poly-nominal $f(s)$ functions with $G^3$ continuity were proposed and justified for its element’s degrees from 4th to 11th, and subtype of $f_\beta(s)$ functions with $G^5$ continuity for its element’s degrees from 6th to 14th (see Fig. 2). Characteristics of these subtype functions constituents were established according to substantial value of coefficient $Z$ (for $f(s)$ function group) and coefficient $U$ (for function $f_\beta(s)$ group). By varying the length $L$ in the TS, and varying the coefficients of its shape $Z$ and $U$ it was possible to find variations along with other parameter values of the curve, which were very close to the etalon graph of the $d\psi/dt$ at the designed height $H$ (see Fig. 1).

\[ \frac{1}{N} \sum_{s=s_b}^{s_e} \left( \frac{d\psi(s)}{dt} \right)^2 \Rightarrow \text{min}, \]  

where $s_b, s_e$ – relative segments of length of the beginning and the end of $\psi(l)$ graph; $N$ – number of points of calculated $d\psi/dt$ function in the interval $s_b \leq s \leq s_e$.

The functional argument is shown by functions that depend on $Z$ & $U$ coefficients values and also on its length $L$. The analytical dependencies of these functions are also given in the previous article [4]. They describe the kinematics of the design point of the vehicle at the height $H$ at given calculated values of the curve with $R$ radios, elevation $D$, velocity of vehicle $V$ and railway track gauge $S$. By symmetrical cant transition $D$ the function $d\psi/dt$ in accordance to these values could be simplified and written as follows:

\[ \frac{d\psi}{dt} = v^2 \left( \frac{d^2 k}{dl^2} \right) + g \left( \frac{d^2 i}{dl^2} \right), \]
where \( k_H \) – curve trajectory function of the design point of the vehicle movement at the \( H \) level; \( i \) – function of lateral track slope and vehicle inclination slope; \( g \) – gravitational acceleration.

Minimization of the function (1) allows bringing the graph of function \( dy / dt \) to its etalon shape. This ensures harmonized conjunction of all of the track + vehicle system elements, at which the highest level of priority aspect of quality functioning could be ensured. The necessary and sufficient \( G^3 \) & \( G^5 \) continuity of functions \( f(s) \) & \( f(s) \) ensure availability of partial derivatives \( \delta^2 \psi / \delta t \delta L \), \( \delta^2 \psi / \delta t \delta Z \) and \( \delta^2 \psi / \delta t \delta U \). It allows the harmonized shape of TS equation to be solved by Newton method.

3. Function Analysis of TS Characteristics of Harmonized Shape

For the purpose of this analysis, we will consider the results of TS shape harmonization of super high-speed railway where the distance between the axes of the track rails \( S = 1600 \) mm, the other parameters are \( R = 8000 \) m, \( D = 150 \) mm, \( H = 2200 \) mm. They were used to assess the parameters of the TS of Order (3,7) shape [1], which was investigated in the previous article [4]. Integrational TS quality characteristics with harmonized properties and the analogical characteristics of the TS of Order (3,7) shape were calculated with MDKM analytical dependencies and with accordance to classical style of tracing of the track axis at RTL (see Fig. 3).

![Fig. 3](image-url)

By analyzing the results, it is possible to conclude that integrational characteristics of the vehicle motion quality on the TS with harmonized characteristics fully correspond to highest requirements indicated in the formalized part of our target as well as in the terms of simple language. They exceed by far integrational parameters of motion quality of the vehicle on previously known TS shapes, as well as that of Order (3,7) shape, which was evaluated by its author as best possible solution [1]. A correct formulation of the target function (1) contributed in obtaining these results as well as proofed regularities of non-linear functions \( f(s) \) & \( f(s) \). This approach helped to eliminate persisting problems in all other TS shapes like significant oscillation amplitudes of \( \psi(l) \) values, also the horizontal line of its central part \( G^0 \) continuity graph of trapezium-shape is approaching the line of minimal velocity \( \psi_{min}(l) \), which corresponds to a hypothetically straight graph \( a(l) \) of the clothoid (see Fig. 3).

For objective reasons this integral index of ergonomic aspect of passenger vehicle motion quality could not be fully respected and maintained at CG. Level. At this level the graph \( \psi(l) \) maintains \( G^0 \) continuity and graduality. But its deflection from trapezium-shape violets to some extent the quasi-linear graph shape of the non-compensated lateral accelerations \( a(l) \). But the dynamics of force interactions between the elements of the track + vehicle system do not deteriorate or worsen practically. This is indicated by gradual and smooth change of rails force reaction graphs \( F_L \) & \( F_R \) (see Fig. 3).

![Fig. 4](image-url)

Fig. 4 The integral indicators of ergonomic and technical aspects of quality, provided on TS with harmonized shape properties in case of mixed traffic movement of both passenger and cargo vehicles with different velocities \( V_{pass} = 120 \) km/h and \( V_{cargo} = 104 \) km/h
This specificity of the track + vehicle system should be considered when designing curve railway tracks for multiple purposes of passengers and cargo movement. When significant differences of design levels of $H$ occur, established in accordance with the priorities of different movement quality requirements for each aspect, the maximum velocity of cargo vehicle with $CG < H_{opt}$ should be less than the optimal velocity of the passenger vehicle. Therefore, when designing curve railway tracks of such kind it should be prioritized the ergonomic quality aspect of passenger vehicle movement. The maximal velocity of cargo vehicle $V_{cargo}$, at which will be obtained the same technical quality requirements of movement as in the previous instance should be calculated in accordance to minimal values of functional (1) with differential derivative implementation of $\frac{\partial^2 \psi}{\partial t^2}V$. Respectively in its functional argumentation (2) it is necessary to take in to account the previously calculated values of $Z$, $U$ & $L$, and to give the designed height $H$ the value CG of the cargo vehicle. The results of this problem solution for TS curve with $R = 665$ m, $D = 150$ mm, $L = 121$ m, are presented in (Fig. 4).

4. Analysis of Harmonized Shape TS Constructional Properties

The difficulties of railway tracks linking with dominant landscape elements and existing infrastructures is mainly dependent on its parameters and the curvature quality. One of the constructive advantages of harmonized shape of TS, which can help in finding an easier solution is that it eliminates vehicle body rocking when passing curved sections of the track. As an outcome the requirement of minimal length of the curved section and straight-line section which should be present in between could be canceled or limited to minimal requirement of 20 m length.

A more obvious constructional advantages of harmonized shape TS are conditioned by its functionally reasonable length, which is normally less than these of traditional TS shapes. Also, its implementation requires much less shifting of the circular curve $p$. It is difficult to prove the objectivity of the results obtained by comparison of different lengths for various TS shapes because of the significant dispersion of its values, which are recommended and applied in cases with similar radiuses, velocities and elevations. In addition, there is lack of information concerning prioritized quality aspects, which affects the argumentation of the proposed lengths. The difficulty of this comparison is illustrated in an example with lengths of $L_{opt}$ polynomials of 9th & 11th degree, which are optimized for motion quality criterion of the vehicle at the beginning and at the end of the TS [3] (see Table).

<table>
<thead>
<tr>
<th>Table Length Comparison of TS of various Shapes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v$, m/s</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>24.26</td>
</tr>
<tr>
<td>30.79</td>
</tr>
</tbody>
</table>

The length of harmonized TS shape $L_{harm}$ compared to them was calculated in accordance to minimal value criterion of functional (1) and with consideration of the same values of additional parameters $S = 1435$ mm & $H = 2200$ mm. Given in Table 1 the $L_{opt}$ & $L_{harm}$ lengths indicate the presence of significant differences in both their values and changing tendencies according to calculated magnitude of non-compensated lateral acceleration $a$. This particularly concerns the length $L_{opt}$ investigated in this article of the TS for the so-called balanced vehicle velocity $v_b = 24.26$ m/s. An almost zero value of the lateral acceleration $a = 0.01$ m/s² within the limits of this velocity will be provided at all levels of the vehicle level only for circular part of the curve with $R = 600$ m and height $D = 150$ mm. But on its polynomial TS shape of 9th degree with the length $L_{opt} = 142.15$ m, the value of this index on designed level $H = 2200$ mm will exceed the allowed limits by 6 times! This is shown by integrative characteristics of motion quality at TS with balanced velocity $v_b$, calculated with MDKM (see Fig. 5).

The character of regularity index for the kinematics of the design point of the vehicle is regulated by factors which are as a rule not taken into the account in traditional models. In this particular instance the influence of vertical part of the graph of the non-lineal cant transition of the external rail height to the alternating values of oscillated reaction forcers of the rails $F_t$ & $F_s$ was critical. In the course of their action the risk of so-called vehicle rocking and the trembling grows. Harmonization of TS shapes helps avoiding this problem. But this requires not only changing the characteristics of $f(s)$ & $f(s)$ functions but also a substantial prolongation of TS length. Therefore, a balanced motion of the vehicle hypothetically could be only achieved at the circular part of the curve, conditioned by the possibility of its construction with relatively big radius and minimal elevation.

A more obvious constructional advantages of harmonized shapes of TS are observed in the results of solving real problems of curve design with estimated values of non-compensated lateral accelerations of more than $a > 0.3$ m/s². With values of $a$ less that these, functionally proved lengths of such TS grow, and with greater values they drop respectively. Because the optimal length $L$ depends on designed values of $V$, $R$, $D$, $S$ & $H$, in each concrete instance it should be calculated along with the $Z$ & $U$ shape parameters at the minimal value of functional (1). As an example, proving this assumption, in Fig. 6, graphs $L$ dependencies from non-compensated values of lateral accelerations $a$ varying in the range from 0.4 m/s² to 0.7 m/s² are put to observation. They were obtained from the results of TS shape harmonization at its circular part $S = 1520$ mm with height $D = 150$ mm for some subtype discretional values of $V$ & $H$. The radius $R$ of each such curve was calculated according to their design value parameters.
The transient curve of the TS axis of the harmonized shape with monotonous graph and $G^4$ continuity has the same curve angle $\beta$, as its equivalent by length and radius and $G^0$ continuity clothoid. Due to a higher grade of smoothness, the associated with it shift $p$ of the circular part of the curve is almost three times less than the $p$ shift of the clothoid. That is another substantially constructive advantage of harmonized TS shape. It allows tracing of the track with existing limitations with higher circular radiuses than those of the clothoids. It also allows substitution of existing clothoid TS shapes of the curves with TS of harmonized shape with minimal shifting of the track axis from its current place. Such design allows increasing the circular radius of the curve to some extent. Eventually it allows to raise the velocity and the quality of train movement, and also reduces the dissociation velocity of the new track geometry in the process of its further exploitation by enhancing the parameters of interaction force dynamics of the track + vehicle system elements.

5. Conclusions

The turning motion of the vehicle with variable curvature and with variable vehicle inclination due to cant transition is a very important aspect of mechanically precise track + vehicle system performance. The seriousness of these problems could be indicated by the abundance of TS solution shapes and procedures [2], which were proposed to address this issue, and to enhance the performance quality. A systematic approach to solving this problem was found by analyzing all previous disadvantages. This solution is based on deterministic physical and geometrical principles of track and vehicle interaction considering the values of its basic construction parameters. Based on these principles, a unique dependence of integral quality characteristics of the track + vehicle system performance was established with the combined harmonization of all parameters of its elements. This dependency is reflected in the formalized target function of their harmonization. The calculated TS parameters in the research process and the optimal value of its length ensure coherent and effective interaction of track + vehicle system elements and high-quality standard of its performance in case of other design parameter values were also respected.

Results of the research and theoretical analysis of functional and constructional particularities of harmonized TS shape properties point to their undoubtedly advantages over traditional and earlier suggested alternative TS shapes for both classical and “up-lifted” tracing. These results also indicate the necessity of optimization and perfecting the evaluation quality criterion for TS railway tracks projects. They should be based not upon segmented quality characteristics of separate construction elements, but rather upon the integrated quality characteristics of the track + vehicle system performance as a total entity.
References


Safety Analysis of Accident During Dangerous Substances Transport

K. Mäkká¹, K. Kampová²

¹University of Žilina, Univerzitna 8215/1, 010 26 Žilina, Slovakia, E-mail: Katarina.Makka@fbi.uniza.sk
²University of Žilina, Univerzitna 8215/1, 010 26 Žilina, Slovakia, E-mail: Katarina.Kampova@fbi.uniza.sk

Abstract

The growth in the use of dangerous goods worldwide also means an increase in the risk associated with their carriage, especially in road transport. The carriage of dangerous substances by road freight transport differs from other types of carriage mainly in terms of technical, operational and safety requirements and conditions. These all contribute to the reduction of hazards and risks. In order to avoid the occurrence of an emergency event or in the case of its occurrence, it is critical to have a well-trained staff with practical experience and knowledge of what to do in an emergency situation. The article describes the expected effects and impacts on the population in the event of an emergency occurrence by dangerous substances transport. The aim of this article is to determine the extent of danger zones in the event of a dangerous substance leakage during transport in a built-up urban area with a high frequency of traffic and population movement.

KEY WORDS: analysis, dangerous substance leakage, safety conditions of transport, simulation, zones of danger

1. Introduction

The transport of fuels by road is a specific type of transport, which is associated with a certain risk that arises from the nature of the transported material. Many authors deal with the issue of risks and its definition. In general, risk is defined as the probability of the occurrence of a negative event and the extent of its effects [1]. Transport routes are mostly led by industrial agglomerations and facilities for their storage and dispensing are situated in areas that are densely populated by the population [2]. Despite the observance of the applicable legal and safety standards and rules, there is a certain probability of an emergency event associated with the leakage of the transported substance [3]. The consequences of this event (fire, toxicity, explosion) can seriously endanger life, public health, damage to property and the environment.

2. Safety of Fuels Transport and Distribution

In providing transportation of fuels, it is necessary to keep in mind that it is not only a matter of protecting the health and safety of the vehicle crew, but also of ensuring the safety and security of all road users and residents of areas adjacent to the road. Constantly increasing intensity and density of road traffic, weather conditions (eg landslides and rocks, snowdrifts and icebergs), indiscipline of road users affect traffic safety and increase the risk of an accident [4].

Fig. 1 Conditions of the safety transport
The safety of fuel transport must be understood comprehensively, i.e. as a set of technical, safety and transport conditions.

Traffic accidents and incidents and associated with fuel leaks have the highest frequency in road transport. The critical factors in this area are [5]:

- Human - fatigue, inattention, arrogant driving, lack of experience, insufficient qualification, non-compliance with regulations on transport, storage and handling of fuel, underestimation of risk, reporting of economic savings (arbitrary shortening of the transport route).
- Means of transport - inadequate technical condition, non-equipment of the vehicle with prescribed means (fire extinguisher), mechanical and technical failures, failure of safety systems, fatigue and hidden errors in construction materials.
- Traffic route and environment - weather conditions, condition of the road, a large number of cars on the roads, rising speed limits, insufficient or missing traffic signs.

According to long-term statistics from different countries, the most common cause of traffic accidents is human in 85% of cases, the road is the primary cause in 10% of cases and the means of transport is the source of accidents in about 5% of cases. Often there are several factors involved in accidents [4].

3. Examples of Selected Emergencies in the Transport of Fuels

Despite the fact that issues of safety and compliance with established standards, rules and regulations for the transport of fuels in road transport pay great attention to the relevant authorities, carriers and drivers, we are sometimes informed about accidents of tanks transporting diesel, gasoline or other dangerous substances.

An example of a more recent accident is overturning and subsequent explosion of a tanker carrying 4,000 gallons of aviation fuel (15,000 l). This event happened on February 20, 2020 in Indianapolis. The fire spread about 500 feet causing severe, catastrophic damage to the pavement and both sides of the bridge.

Another emergency event in the fuel transport process is the leakage and subsequent explosion of fuel while unloading, which happened in Roma on December 5, 2018. Consequences of accident: 2 people died after another 17 people, six of them in critical condition, were taken to hospital by two helicopters and eight ambulances [6].

According to initial reports, a fire broke out while the truck was unloading the fuel, followed by a massive explosion that swept the truck a dozen meters onto the opposite side of the road.

Fig. 2 A tanker overturned and caught on fire on Indianapolis' east side (Indiana State Police)

Fig. 3 A fuel tanker truck exploded while unloading its cargo at a gas station (Italian news agency ANSA)

Fig. 4 A truck that was transporting flammable substances explodes after colliding with another truck on a highway in the outskirts of Bologna (Italian news agency ANSA)
The last example of selected accident happened on August 6, 2018 in Italy. A tanker truck carrying a highly flammable gas (liquefied petroleum gas, otherwise known as propane) exploded after rear-ending a stopped truck on a crowded highway near the northern Italian city of Bologna. At least two people were killed, up to 70 injured and part of the raised expressway collapsed in the fireball.


The aim of the case study is to determine the extent of the danger zone in the event of a gasoline leak in a built-up urban area with a high frequency of traffic and population movement. Examples of the above-mentioned emergency events also prompted the elaboration of a study focusing on urban development with a high concentration of inhabitants. The consequences of such events can cause injury or death to a large number of people.

In the Slovak Republic, fuels are most often transported by road by road tankers of a tractor with a semi-trailer. Individual tank sets are multi-chamber (up to 6 separate chambers) with the possibility of transporting individual types of fuel at once, in different volumes, from 20,000 l up to 50,000 l.

For the purpose of the case study, an emergency scenario was modeled: during the transport of gasoline, the entire transported amount of gasoline leaked from the tank in a built-up urban area with a high frequency of traffic and population movement. Estimated population density at the accident site 160 persons/ha. Source of risk: tank with a volume of 46 m³, transported amount of petrol: 36,800 kg.

Currently, there are many software products available that allow scenario building and risk assessment [7, 8]. Software products are based on physical models, they allow to take into account the influence of working conditions, properties of leaking substances and environmental influences on the extent of damage and contamination, which not only speeds up the calculation but also refines the data obtained [9].

The simulation tools ALOHA and EFFECTSGIS were chosen for the purpose of simulating the consequences of an emergency event connected with the leakage of transported fuels.

The ALOHA (Areal Locations of Hazardous Atmosphere) program is a tool for determining the consequences of a leak of hazardous substances. It contains a database of the most frequently used chemical substances and their physico-chemical properties. The result is the determination of the expected limit of the injuring or lethal concentration of a dangerous substance in the field, it displays the results in text and graphic form [10]. Practical experience with the use of this software shows that the identified affected areas are conservative and thus represent the worst possible accident scenarios [11].

The modeling program EFFECT allows to determine the manifestations such as pressure wave, thermal radiation and gas concentration. It determines the consequences of an accident, e.g. human mortality, first and second degree burns, lung and ear drum damage. The advantage of this program is complex calculations from the initial physical effects to the consequences of the accident.

The consequences of the emergency scenario were modeled in two representative types of weather conditions:

- normal air stability 4th class = D, medium wind speed - 5 m/s (most common conditions during the year);
- very stable conditions 1st class = F, wind speed low - 1.7 m/s (worst dispersion, affected largest area - worst case scenario).

Table 1

<table>
<thead>
<tr>
<th>Emergency scenario</th>
<th>Road truck</th>
<th>Atmospheric stability D</th>
<th>Atmospheric stability F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaked gasoline does not burn, it evaporates into the atmosphere</td>
<td>Toxic effects of cloud vapor **</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A flammable cloud forms</td>
<td>60% LEL 20</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10% LEL 87</td>
<td>154</td>
</tr>
<tr>
<td></td>
<td>Explosion of vapour clouds</td>
<td>Serious damage to buildings [m] &lt; 10 38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Danger to persons from serious injuries [m]</td>
<td>&lt; 10 39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Danger to persons from serious injuries [m]</td>
<td>&lt; 10 43</td>
<td></td>
</tr>
<tr>
<td>Leaking gasoline burns to form POOL FIRE</td>
<td>Potentially fatal danger to persons from thermal radiation [m] 30</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

In the event of an emergency associated with the leakage of the entire amount of gasoline from the tank, a potentially fatal person will be at risk at a distance of 30 m from the crashed tank (Table 1). The number of people at risk of an emergency was calculated from a formula (1)

\[
N = A \cdot PD
\]

where \(N\) is the number of persons at risk; \(A\) is the total affected area (affected area) [ha]; \(PD\) is the population density in the affected area [number of persons / ha].
Given the population density (160 inhabitants per hectare), 11.3 people will be potentially fatally injured. During the initiation and subsequent explosion of the escaped vapor cloud, the consequences of the explosion are worse in the case of atmospheric stability type F.

<table>
<thead>
<tr>
<th>Emergency scenario</th>
<th>Road truck</th>
<th>Atmospheric stability D</th>
<th>Atmospheric stability F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool fire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potentially fatal danger to persons from thermal radiation [m]</td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2nd degree burns at a distance from the flame [m]</td>
<td>65</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>1st degree burns at a distance from the flame [m]</td>
<td>88</td>
<td>88</td>
<td></td>
</tr>
</tbody>
</table>

When modeling with the EFFECTSGIS program, only thermal radiation hazard zones were determined for the modeled emergency leakage scenario. When a pool of leaked gasoline burns, people within a radius of 50 m are potentially fatally endangered by the thermal effects, which at a specified population density are 31.4 inhabitants (calculated from formula 1). The occurrence of 2nd degree burns was determined at a distance of 65 m and 1st degree burns at a distance of 88 m from the leak site (Table 2).

5. Conclusion

From the analysis we carried out, it is easy to imagine the danger posed in the event of an emergency for the inhabitants of the inhabited area by a 46 m³ petrol tank truck. The worst-case scenario assumes a fatal threat to 32 inhabitants within a radius of 50 m from the initiation site.

The main aim of this article is to provide practical example in assessing the risks associated with the transport of dangerous substances in built-up and densely populated areas. The results could be useful in various studies of the societal and environmental risks associated with accidental releases of hazardous substances when measures are proposed to prevent or mitigate the consequences of these events.

Acknowledgements

This paper is an output of the science project Vega 1/0628/18 Minimizing the level of experts’ estimations subjectivity in safety practice using quantitative and qualitative methods.

References

Investigation of the Efficiency of Small Electric Ship Propulsion and Battery Energy Control Systems

V. Djackov¹, E. Guseinoviene¹, V. Jankunas¹, T. Zapnickas²

¹Klaipeda University, Bijunu 17, Klaipeda, Lithuania, E-mail: vasilij.djackov@ku.lt
²Klaipėda University, H. Manto 84, Klaipėda, Lithuania, E-mail: tomas.zapnickas@gmail.com

Abstract

With the development of the shipping sector, the amount of fuel consumption in the maritime sector has increased. It leads to an increase in greenhouse gas (GHG) emissions from shipping. When the emission rates of the transportation sectors have been examined, it became clear, that the maritime sector has low value compared to other transportation ways, but it still reaches approx. 2.5% of the global value. As the International Maritime Organization (IMO) limits GHG emissions from ships, the idea of the green ship has become a globally important issue. Renewable energy sources are used for the implementation of green ship idea. One of these is to use electrical ships. The advantages of all-electric or hybrid driven boats are the reductions in pollution, noise, vibration, and potentially, cost. This paper presents the case analysis of a small scale ship energy consumption and power supply energy estimation. An experiment was carried out to estimate real battery capacity and the charging/discharging capabilities of the propulsion created system.

KEY WORDS: Small electric boat, Energy efficiency, Energy power source capacity, Battery management system

1. Introduction

Nature friendly transportation means became more popular in recent years due to ecological problems caused by emissions from different sectors of industry and transport [15]. The emissions from the transport section are taking a significant part in comparing to total emissions produced by all sectors. In the European Union greenhouse gas emissions from the transport reaching more than 30% [17]. In this regard nowadays shipping is regulated with various standards and regulations to reduce the impact on nature and to increase the vessel’s energy efficiency [16]. One of the possible solutions that could allow reducing the emissions from transport is the usage of electric drive systems. Although the electric driven ship has such advantages as zero emission, low noise and vibration, the economic indicator is still heavily influencing the development of this technology. Electric or hybrid propulsion systems are rarely implemented on the vessels bringing cargoes for long distances due to the main power source price and endurance limitations. In this case traditional fossil fuel driven propulsion systems still have more advantages by the weight and energy density factors [22].

However electric and hybrid propulsion systems are quite effective in specific shipping applications, where the vessel is operating in short range distances and needs to use multiple propulsion regimes (maneuvering, mooring) in its operation. The electric propulsion system consisting of an electric motor, energy source, frequency converter and other components is a very nice example of the technology application. It allows using stored or generated electric energy for the movement of the vessel and for work of the vessel's auxiliary systems. Energy storage allows using of electric energy in mobile transport systems generated by alternative power sources.

The electric propulsion system and its components are still in the development stage and the components like energy storage are still quite expensive. They are being improved to increase their energy density and to reduce production costs. However existing achievements in this field are giving the possibility to improve complex electric propulsion systems by combining and optimizing energy control systems. The choice of the system components and their parameters, energy control system optimization is a difficult process, requiring to evaluate many different factors. To create an effective electric propulsion system nowadays it is necessary to develop and to improve existing algorithms and simulations.

There is a number of research and development projects oriented towards the creation products and technologies of low emission or zero emission vessels. Vessel hybridization or electrifications processes are tackled in such projects as E-FERRY, ELEMED, TRAM, ELMAR [18-21]. The experiences of conversion of one of the ELMAR demo projects are described in this article. For the conversion demo project 8,5 meter long rescue boat with the internal combustion engine of 30 kW was taken to convert it into an electric driven pleasure boat. After a deep modernization process, the boat will have a nicely furnished cockpit and superstructure (Fig. 1). It will be driven by an EMRAAX188 electric motor with continuous output power up to 15 kW (max).

2. Possibilities and the Choice of Electrochemical Energy Storage

Limited resources of fossil fuels, regulations on the reduction of airborne emissions and the threats of global warming forces us to choose alternative energy sources such as wind, solar or waves as the main power source for the
boat propulsion [1, 2].

![Fig. 1 Visualization of the electric driven demo boat project](image)

The electric boat will receive the energy from the shore connection (which can be generated from wind, photovoltaic power plants, etc.) and/or from the installed solar panels. There are different possibilities to store this energy on the boat: Mechanical Energy Storage (Compressed Air Energy Storage, Flywheel Energy Storage), Electromagnetic Storage (Superconducting, Supercapacitor) and Chemical Energy Storage (Metal Air Batteries, Fuel Cells, Typical Batteries) [3, 4]. Considering energy storage practicality and commercial availability, it was decided to use electrochemical batteries on the boat as the main energy storage.

At the moment the choice of commercially available electrochemical batteries is quite wide: Pb-Acid (lead acid), NiMH (nickel metal hydride), NiCd (nickel cadmium), NiFe (nickel iron), Li-Ion (lithium ion) [5]. The average values of the batteries parameters are compared in the Table [3, 6].

<table>
<thead>
<tr>
<th></th>
<th>Pb-Acid</th>
<th>NiMH</th>
<th>NiCd</th>
<th>NiFe</th>
<th>Li-Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy</td>
<td>30-50</td>
<td>50-80</td>
<td>50</td>
<td>30-50</td>
<td>75</td>
</tr>
<tr>
<td>Energy Density</td>
<td>55</td>
<td>180</td>
<td>100</td>
<td>55</td>
<td>250</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>50-70</td>
<td>65</td>
<td>65-70</td>
<td>55-65</td>
<td>60</td>
</tr>
<tr>
<td>Self-discharge (%/month)</td>
<td>30</td>
<td>30</td>
<td>28</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Cycle Life (cycles)</td>
<td>300-500</td>
<td>500-800</td>
<td>1500</td>
<td>2000</td>
<td>500-3000</td>
</tr>
</tbody>
</table>

Lead Acid battery technology is well developed, but they can cause inconveniences when installed in a boat: they must not be stored in closed containers - they must be ventilated and their electrolyte levels must be monitored, otherwise they may dry-out [7]. Although Nickel Cadmium batteries perform better than Lead Acid, the limitations of their use increase due to the presence of toxic Cadmium in the batteries [8]. In addition, Ni-Cd-related CO₂ emissions are significantly higher than for Li-Ion [9]. Ni-Fe batteries have a higher Cycle-life compared to Pb-Acid, Ni-Mh or Ni-Cd [10]. However, the specific energy of Ni-Fe batteries is lower, so the limited boat space will result in less energy being stored. Compared to other batteries, Li-Ion batteries have a high Specific Energy (more energy in the same space), a significant Cycle Life (lower Service Costs) [11], a low Self-discharge (higher useful use of stored energy). With this in mind, it would be best to use Li-Ion batteries to store energy in an all-electric boat.

One source of batteries – used EV batteries [12]. A 70 kWh battery pack was used in a Tesla S battery electric vehicle (BEV) was purchased for this boat. The package consists of 14 modules. Physical parameters of the module:

- length – 685 mm;
- width – 300 mm;
- thickness – 78 mm;
- weight – 25 kg.

The module consists of cylindrical Li-Ion Panasonic cells using an NCA (Nickel Cobalt Aluminum) cathode [13]. Cell connection configuration in the module: firstly a group of 70 cells in parallel, then these 6 groups in series (Fig. 1 - C101 ... C670), thus obtaining a 24 V module. By connecting the cells in this way, the highest battery efficiency and the best cell utilization are obtained [14].

Every module has a Slave BMS (battery management system) (Fig. 2 - Slave BMS; Fig. 3 - 3).

After receiving the command from the Master BMS via the Data Line (Fig. 2; Fig. 3 - 4), the Slave BMS balances the cell groups specified in the command using the passive balancing method. Slave BMS also measures:

- cell group voltages;
- module voltage;
- using thermistors (Fig. 2 - NTC1 and NTC2; Fig. 3 - 2) temperatures at the module contacts (Fig. 3 - 1).

This data is sent to Master BMS. The Slave BMS has a built-in safety function: if the voltages and / or temperatures of the cell groups fall outside the limits set in the memory of the Slave BMS, a fault signal is sent to the Master BMS via the Data Line.
Since the boat will be powered by a low-voltage motor-controller system, the boat's power source is designed from 3 groups of series-connected modules connected in parallel, thus obtaining a 72 V battery (Fig. 4 - M11 .. M33).

The labmade Master BMS communicates via the Data Line with the modules Slave BMS (Fig. 4). In addition, the Master BMS uses the Current Sensor to measure the battery current and calculate the SOC (state of charge).

A user-friendly HMI (human-machine interface) (Fig. 3), which provides the user with information from the Master BMS and allows the user to control the Master BMS. The HMI has a built-in Data Logging feature that allows you to store battery performance data.

3. The Experiment

Before the experiment, the battery was charged, at the end of the charging the cell voltage was about 4.2 V. During the experiment, the battery was loaded with forced cooling unregulated resistive load. The load resistance was chosen to simulate an average load of 8 kW. The battery was placed in an open bench in an enclosed space without active cooling.

At the beginning of the experiment, before applying the load, the battery voltage reached 74.6 V. The experiment lasted 6 hours and 15 minutes. At its end, after disconnecting the load, the battery voltage had dropped by 14.8 V compared to the beginning of the experiment (Fig. 5).
At the beginning of the experiment the internal resistance of the battery was 5.6 mΩ, at the end of the experiment it rose to 6.4 mΩ.

Since the load resistance was not adjustable, the battery current varied from 141.8 A to 114.2 A during the experiment. During the experiment, the battery delivered 794 Ah of charge (Fig. 5) and generated 52.6 kWh of energy. During the experiment, the measured temperatures at 24 points of the module changed insignificantly (Fig. 6). The lowest recorded temperature value was 21.7°C and the highest was 26.1°C. The small and non-current-correlating ($r^2 = 1.5\%$) temperature change suggests that the battery temperature was not affected by the battery discharge processes.

The median voltage of the cells of the battery 5040 was 4.17 V before switching on the load, and when it was switched off, the voltage dropped 0.82 V compared to the voltage before switching on the load (Fig. 7).

![Fig. 7 Voltages of cells during the experiment](image)

In the graph in Fig. 7, the min and max values of cell voltages visible up to the 5800 s time stamp was influenced by the cell balancing process.

4. Conclusions

1. By replacing the internal combustion engine system on the pleasure craft with a power plant, we have achieved several goals that are currently relevant to the world: we have reduced CO$_2$ emissions and potential water pollution to zero.
2. Although the system had already used batteries installed, the possibilities of the pleasure boat remained solid: for a group of five to ten people cruising at the speed of 10 km/h it can sail up to 60 km (electric motor power 7-10 kW).
3. The battery can be safely charged with 140 A without worrying about thermal management.
4. Further investigations will be carried out to estimate the efficiency of the created propulsion and battery energy control systems in real exploitative conditions.

Acknowledgements

The authors acknowledge EU project No: STHB.01.01.00-DE-0090/16 ELMAR – Supporting South Baltic SMEs to enter the international supply chains & sales markets for boats & ships with electric propulsions.

References

Dynamic Assessment of Critical Infrastructure Resilience in Airport Landside

Z. Korecki\textsuperscript{1}, J. Kozuba\textsuperscript{2}, J. Šafranko\textsuperscript{3}

\textsuperscript{1}University of Defence in Brno, Kounicova 65, 602 00, Brno, Czech Republic, E-mail: zbysek.korecki@unob.cz
\textsuperscript{2}Silesian University of Technology, Akademicka 2A, 44-100 Gliwice, Poland, E-mail: Jaroslaw.Kozuba@polsl.pl
\textsuperscript{3}University of Defence in Brno, Kounicova 65, 602 00, Brno, Czech Republic, E-mail: jan.safranko@unob.cz

Abstract

The paper analyzes the objects in the airport landside area according to selected factors - size, resistance to mobile road transport, explosives, and impact on air traffic security. The aim of the paper is to propose selected measures to increase the level of safety based on the analysis of the access transport network and the possible impacts of explosions in the airport vicinity.

The method "Research, development, testing, and evaluation of critical infrastructure elements" is the basis for calculating the threat level of the current urban condition, buildings resilience, including roads network.

The authors will analyze the airport landside Brno-Turany (LKTB) and Karlovy Vary (LKKV).

KEY WORDS: critical infrastructure, anthropogenic threats, explosion, impact of the vehicle, airport landside model.

1. Introduction

When selecting the impact force, it is necessary to take into account the expected consequences of a building failure due to impact, local conditions, and the specific place and orientation of the structure.

The effects of an explosion vary depending on the type of explosion. There is air, ground, underground, and underwater explosion that have different effects.

The air blast creates over pressure at the head of the shock wave, the ground-shock releases the explosion energy into the ground and spreads through the geological environment, and fragments have primary and secondary phases.

Another result of an explosion is the crater ejecta, which creates the soil erosion in-depth, and by creating mounds and heat creates a fiery area in the explosion vicinity.

The TNT equivalent of non-industrial explosive mixtures is 0.7 - 0.9 compared to industrial values.

The waves propagate from the focus of the explosion in spherical or hemispherical wave surfaces.

The ground explosion at height $h$ above terrain shall be converted to the equivalent charge mass $C_w$ by the multiple of the real charge mass $C$ used \cite{1} according to the formula:

$$C_w = 2C - C \frac{h}{20}, \text{ for } h \leq 20 \text{ m} ;$$

$$C_w = C, \text{ for } h > 20 \text{ m} .$$

According to the IAEA, the impact of large bodies or small bodies is different.

The shock calculation corresponds to the usual rules of structural dynamics, where the energy comparison is to calculate the energy of the shock $E_a$ transmitted to the obstacle-according ratio to $m/M_e$, where $M_e$ is the effective mass of the obstacle (inertial mass), to the formula:

$$E_a = \frac{1}{2} M_e V_e^2 t, \text{ if } \frac{m}{M_e} \leq e ;$$

$$E_a = \frac{1}{2} M_e V_e^2 t + \frac{1}{2} m V_e^2 t ,$$

where $M_e$ is the effective mass of the obstacle (inertial mass); $V_e$ velocity of the flying object after impact:

$$V_e = \frac{V_0 \left[ \frac{m}{M_e} - e \right]}{1 + \frac{m}{M_e}}$$

and $V_t$ is the obstacle velocity after impact:
\[ V_i = \frac{m/M}{1 + \left( \frac{m}{M} \right)^2} \left[ V_0 \left( 1 + e \right) \right], \]  

where \( m \) is the effective mass of the incident object – inertial mass, \( V_0 \) the velocity of the flying object before impact in the normal direction and \( e = V_i / V_e - 1 \) is the restitution coefficient.

According to the empirical formula, the perforation thickness of the reinforced concrete slab is a solid flying object [2]:

\[ t_p = \frac{1}{320} \left( \frac{U}{V} \right)^{0.25} \left( \frac{mV}{gD_i k} \right)^{0.5}, \]  

where \( U \) is the reference velocity of 61.0 m / s; \( V \) the velocity of the object’s impact in m/s; \( m \) – the mass of the object in kg; \( g = 9.81 \text{ m/s}^2 \) is the gravitational acceleration in Mpa. The plate is expected to break with cracks at 1.3 tp and above, but should not be destroyed.

The air traffic has experienced unprecedented development in the last decade, which has been supported by the technologies development and services provided levels.

However, at the beginning of March 2020, air traffic over Europe decreased much because of measures against the spread of Covid-19. Not only airlines but also important public services will have the effects of a pandemic.

The reduction in the number of flights from the end of February is significant and changes from 28,999 movements on 28 February 2020 to 15,200 on 17 March 2020. A further reduction in the number of flights to 3,575 was recorded on 28 March 2020.

The economic impacts of reduced air traffic will be reflected in the number of airlines, employees, and negative impacts on the development of airport infrastructure.

Temporary restrictions on air traffic cannot affect the security measures development, the maintenance of a reliable level of critical infrastructure protection, which remains a key task for states.

The European Union continuously issues directives that help nation states to take measures to protect their critical infrastructure facilities against attack.


Critical infrastructure buildings can be exposed to extreme loads, so it is necessary to use modern building technologies and materials during planning and construction. The level of risk of a terrorist attack may change periodically, but measures to protect CI entities are taken continuously with a certain level of prediction.

The construction of buildings in the airport landside must be designed with sufficient resistance to the case of blast waves generated by explosions [4, 5].

The building materials of CI buildings must include cement-based composite, steel, and glass materials with resistance explosion or impact.

Airport landside are infrastructure facilities with a high concentration of people and mobile resources, as well as areas where logistics centers are concentrated. At the same time, it is necessary to keep in mind that leisure centers will be developed in the near future to satisfy air transport customers.

Newly built modern interiors and exteriors within airport cities [6] with transport infrastructure developed, allow smooth transport between airport and center.

Further urban development must do synergies between the requirements for the explosion resistance of structural systems while ensuring the people protection.

The solution complexity is given not only by the general design requirements but also by the increasing requirements for hygienic standards [7].

The increase in CI protection in the Airport landside area must be based on knowledge of the explosion load, the type of explosion and the explosion distance from the object, or the energy of a mobile device that penetrates into the load-bearing elements of buildings with unspecified speed and weight.

Knowledge of the properties of building materials, including the level of resistance, is odellin in many scientific studies and articles [8, 9].

The shapes diversity, sizes, and different building materials in a relatively enclosed space requires the use simulations and mathematical resistance odelling to make sure high mobility inside and outside buildings while implementing protective elements that will make sure high explosion resistance [10-12].

Explosives, depending on their properties and composition, have different characteristics and therefore different effects on objects [13]. The urban element resistance to pressure waves depends on the shape and building materials used [14-17].

Three types of tests – non-destructive tests (NDT), semi-destructive and destructive methods [18], realize knowledge of changes in physical and mechanical properties of building materials. Other important factors are time and the effect of temperature differences.
2. Explosions and Blast Phenomenon

An explosion is defined as a large, rapid, and sudden energy release. Explosions can be categorized based on their nature as physical, nuclear, or chemical events. In a physical explosion, energy can be released from compressed gas, volcanic eruptions, or by merging two liquids at different temperatures. In a nuclear explosion, energy is released from various atomic nuclei by redistributing protons and neutrons inside the interacting nucleus. The main source of energy, in the case of chemical explosions, is caused by the rapid oxidation of carbon and hydrogen.

Explosive materials can be classified according to their physical state as solids, liquids, or gases. They can also be classified as secondary or primary explosives based on their sensitivity to ignition. Primary explosives, which are initiators, contain lead azide and lead styphnate and are used to ignite secondary explosives. Bolstering explosives are secondary explosives that include TNT, RDX and octogen (HMX), and tetrazene. Secondary explosives are intended to be exposed under certain conditions. The distribution of secondary explosives is based on the main component. If the main component is TNT, it is “castable.” If the main component is a crystalline explosive, it is a plastic explosive.

Further secondary explosives division can be according to the chemical structure, where they are divided into nitroaromatics (TNT), and nitramines (RDX).

An explosive process is a physical or chemical process in which energy is rapidly released from a system. At the same time, the temperature and pressure near the exploding system increase. Detonation is a rapid exothermic reaction, burning at supersonic speed, where a shock wave destroys the surroundings with a destructive explosion.

A detonation wave is a shock wave supported by a chemical reaction-propagating explosive at a constant rate in layers of explosive perpendicular to the direction of propagation of the reaction. The detonation speed is greater than the speed of sound, where the reaction spreads by transferring energy to the entire explosive. The speed of the shock wave must be faster than the speed of sound in an explosive. The speed of sound reaches a level in laboratory conditions $c = 340 \text{ m/s}$ [19].

The detonation initiates a shock wave from the place of the explosion into the surrounding environment, while a pressure change occurs. We distinguish pressure waves into:

- a shock wave, where there is a step change in all state quantities of the material such as pressure ($p$), temperature ($T$), density ($\rho$) or specific volume ($V$) and energy $\epsilon$;
- an air shock wave, which arises during the explosive detonation, when compressed gaseous products expanding in all directions and the front of the air shock wave push air in front of it, which in the first phase is accompanied by flue gases. With increasing distance from the explosion, the flue gases movement stops, the shock wave moves through the environment and changes to an acoustic wave;
- an acoustic wave, which is a mechanical wave advancing through an elastic medium. The strength of the sound depends on the amplitude of the wave and the frequency of the waves in the frequency range of 20 Hz to 20 kHz;
- reflected air shock wave arises as the difference between the incident pressure wave on the obstacle and the reflected pressure wave. The magnitude of the reflected wave depends on the angle of incidence.

The size calculation is calculated according to the formula:

$$\Delta p(t) = \Delta p_0 e^{-t/\tau} \left(1 - \frac{t}{t_1}\right),$$

where $t_0$ is the reaction start time [s]; $t_1$ is the duration of the overpressure phase [s]; $t_2$ is the duration of the underpressure phase [s]; $p_0$ is the measured pressure [Pa]; $p_0$ is the overpressure at the front of the air shock wave [Pa]; $p_{\text{max}}$ is the maximum pressure of the air shock wave [Pa]; $p_\text{atm}$ is the atmospheric pressure [Pa]; $i_p$ is the pulse of the overpressure phase [Pa × s]; $i_{p_\text{u}}$ is the pulse of the underpressure phase [Pa × s].

The most important parameters characterizing the shock wave or pressure wave are: the overpressure at the front of the air shock wave $p_0$, the duration of the overpressure phase $t_1$ and the impulse of the pressure wave $i_p$.

In simple terms, the pressure wave pulse can be expressed by the equation [20]:

$$i_p = \frac{1}{2} p_0 t_1.$$

The main parameters influencing the effect of the air shock wave are the overpressure on the forehead and the impulse of the overpressure part.

From the propagation point of view, it is necessary to take into account whether the explosive is located in an unbounded space and thus propagates in all directions, or whether the explosive detonates on the surface and the wave propagates only in the hemisphere.

The energy amount is greater. For this reason, overpressure and impulse are also higher. The TNT equivalent is most often used to express the effect.
The TNT equivalent is introduced for easier interpretation. It is a conversion of the size of the charge of the considered explosive to the charge of TNT, which has the same effect (overpressure and impulse). At the same time, its effect causes an air shock wave of the same parameters as the tested explosive with the same destructive force.

The conversion can be used for clouds of gas, vapor or clouds of dust within the explosive limits, also for condensed explosive. The TNT equivalent can be determined experimentally or it can be calculated from the values of explosion heats according to the equation:

\[ w = \frac{\eta Q E_c}{E_{TNT}} \]  \hspace{1cm} (10)

where \( w \) is equivalent to the mass of TNT [kg]; \( Q \) - amount of exploded gas [kg]; \( E_c \) - is the heat of combustion of gas [kJ × kg⁻¹]; \( \eta \) - explosion efficiency [-]; \( E_{TNT} \) - combustion heat TNT [kJ × kg⁻¹].

From the TNT equivalent of the charge mass, the characteristics of the pressure wave can be estimated based on the maximum over pressure at the front of the wave to any distance from the epicenter of the explosion.

The range of a pressure wave is the distance that a pressure wave of appropriate over pressure \( \Delta p \) at its front can reach, giving valuable information about the effect of the "injuring force" around the epicenter of the explosion.

The pressure wave maximum over pressure, which is based on empirically determined data, is expressed by the equation:

\[ \Delta p = \left( \frac{93.2}{Z} \right) + \frac{383}{Z^2} + \frac{1275}{Z^3} \]  \hspace{1cm} (11)

The reduced distance is calculated according to the formula:

\[ Z = \frac{R}{w^{0.3}} \]  \hspace{1cm} (12)

where \( Z \) - reduced distance [m]; \( R \) - distance from the epicenter of the explosion [m] and \( w \) - TNT equivalent [kg].

The amount of energy transferred to the total weight of the explosive via the detonation wave is 1-10MPa. The conversion speed is in the range of 340 – 10 000 m/s.

Measurable parameters of the explosive are important for comparing the force and destructive effects, as well as determining which type of work is suitable [21].

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Explosive parameters [22]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of fumes after the explosion</td>
<td>Volume of gases in liters produced by the explosion of one kilogram of explosive when converted to a temperature of 20°C</td>
</tr>
<tr>
<td></td>
<td>500 – 1 000 l/kg</td>
</tr>
<tr>
<td>Explosion temperature</td>
<td>The highest temperature reached by the gases created by the explosion</td>
</tr>
<tr>
<td></td>
<td>2 500 – 5 000°C</td>
</tr>
<tr>
<td>Explosive energy (( E_0 ))</td>
<td>the amount of energy is released by the explosion of 1 kg of explosive</td>
</tr>
<tr>
<td></td>
<td>industrial explosives – 4,000 kJ/kg, military explosives – 6,000 kJ/kg</td>
</tr>
<tr>
<td>Detonation velocity (( D ))</td>
<td>the rate of propagation of an explosion at the moment of explosion, expressed in m/s or km/s</td>
</tr>
<tr>
<td></td>
<td>industrial explosives 2,000 - 5,000 m/s, military explosives 6,000 - 8,000 m/ s</td>
</tr>
<tr>
<td>Explosive density (( \rho ))</td>
<td>it decides very significantly on the course of the explosion</td>
</tr>
<tr>
<td></td>
<td>when the density of the material is exceeded, detonation defects occur and the explosive explodes only partially or not at all</td>
</tr>
</tbody>
</table>

Brisance defines the direct destructive effect of detonation. It is defined as the product of the detonation velocity in km / s, the explosive density in g/cm³ and the explosion energy in kcal / kg according to the equation [23]:

\[ B = D \rho E_0 \]  \hspace{1cm} (13)

where \( B \) is brisance; \( \rho \) is explosive density [g/cm³]; \( E_0 \) – explosion energy [kcal/kg].

A secondary explosion during detonation causes an explosion of a (shock) wave, which leads to extensive damage to the surroundings. The explosive detonation generates hot gases under the pressure of up to 300 kilobar and at the temperature within the range of 3,000 to 4,000°C. The explosion initiates the release of the chemical energy of the charge, and at the same time causes the shock wave formation, accompanied by the formation of chemical transformation products. The hot and compressed products of the explosion expand into the environment in the surrounding gaseous medium, the products of the explosion initially moving together with the shock wave front. Subsequently, the mass particles of the flue gas at the distance of 9-19 diameters of the original charge slow down, and
the shock wave front separates from the flue gas. The separate shock wave front continues as an air shock wave. Due to the action of the geometric growth factor of the surface area and the gradual conversion of the wave energy into thermal energy, the transmission energy decreases with increasing distance from the reflected. After a short time, the pressure behind the front drops below the ambient pressure. In the negative phase, a partial vacuum is created, which sucks in air with debris carried at a great distance from the source of the explosion.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>v (mm/ms)</th>
<th>a (mm/ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>626.28</td>
<td>2053.1</td>
</tr>
<tr>
<td>2</td>
<td>332.01</td>
<td>317.49</td>
</tr>
<tr>
<td>3</td>
<td>225.28</td>
<td>152.08</td>
</tr>
<tr>
<td>4</td>
<td>1096.5</td>
<td>1019.8</td>
</tr>
</tbody>
</table>

2.1. Explosive Air Blast Loading

The explosion efficiency of a conventional bomb is defined by the weight of the charge ($W$) and the distance between the explosion and the target.

The physical properties of the source of the explosion affect the airwave properties. Fig. 1 shows a typical high-pressure profile.

![Fig. 1 The ideal shape of an air pressure wave [24]](image)

At the time immediately after the explosion $t_o$, the pressure reaches the maximum value of the over pressure, $P_{so}$, above the ambient pressure, $P_0$.

The pressure is then equalized to the ambient level and further decomposes to $P_{so} - $ at time $t_d$ before finally returning to the ambient conditions at time $t_d + t_d^-$. The amount of $P_{so}$ is usually referred to as the peak overpressure. Above the pressures $P_{so}$, the impact peak is amplified by the reflection factor when the shock wave hits an object or an obstacle in the way. The reflection factors depend on the intensity of the shock wave. The reflection factors occurrence can increase the incident pressures by up to the order of size.

Throughout profile the pressure-time, there are two main phases: the positive phase with duration $t_d$, and the negative phase with duration $t_d^-$. The negative phase has a longer duration and lower intensity than the positive phase. As the distance and duration of the uplink wave of the positive phase increases, the shock pulse has a lower amplitude and a longer duration. As the pressure progresses, the entire structure is absorbed by the shock wave. The negative phase increases the damage to the structure of the object caused by flying debris (Fig. 2).

![Fig. 2 Blast loads on a building [25]](image)

If the exterior walls of a building are able to withstand a frontal impact load through openings for windows and doors, it can be predicted that the interior structure and people are exposed to a pressure wave and moving material particles. The building elements unable to withstand the shock wave break and are further fragmented, moving by the dynamic pressure that immediately follow the shock front. Parts of buildings, construction, and other materials will move in the direction of wave propagation. In this way, the explosion will spread through the building.
2.2. Blast Wave Scaling Laws

All parameters of the explosion are primarily dependent on the amount of energy released by detonation in the form of a shock wave and the distance from the explosion.

A universal normalized description of the effects of an explosion can be achieved by varying the distance with respect to \((E/P_0)^{1/3}\) and the pressure ratio with respect to \(P_0\), where \(E\) is the energy released (KJ) and the ambient pressure (usually 100 kN/m\(^2\)).

The equivalent mass of TNT represents the basic unit used for the conversion of other explosives (charge mass \(W\)).

The results are then given as a function of the dimensional distance parameter (reduced distance) \(Z = R/W^{1/3}\), where \(R\) is the actual value of the effective distance from the explosion. \(W\) is generally expressed in kilograms.

Pressure wave parameters for conventional high explosive materials were the subject of many studies in the 1950s and 1960s. Estimates of the highest overpressure due to a spherical explosion based on an adjusted distance scale \(Z = R/W^{1/3}\) were calculated by scientists [26-28]. The authors described the movement of the pressure wave through the air.

If a vertical obstacle is placed in the way of a pressure wave, the reflection increases the over pressure to a maximum reflected pressure \(P_r\) as:

\[
P_r = 2P_{SO} \left( \frac{7P_0 + 4P_{SO}}{7P_0 + P_{SO}} \right).
\]

A complete discussion and extensive graphs related to the pressures and duration of the explosion were published by Mays and Smith [29].

An overview of peak reflected overpressures is given in Table 3.

| Peak reflected overpressures \(Pr\) (in MPa) with different \(W-R\) combinations |
|---|---|---|---|---|
| 100 kg TNT | 500 kg TNT | 1000 kg TNT | 2000 kg TNT |
| 1 m | 165.8 | 354.5 | 464.5 | 602.9 |
| 2.5 m | 34.2 | 89.4 | 130.8 | 188.4 |
| 5 m | 6.65 | 24.8 | 39.5 | 60.19 |
| 10 m | 0.85 | 4.25 | 8.15 | 14.7 |
| 15 m | 0.27 | 1.25 | 2.53 | 5.01 |
| 20 m | 0.14 | 0.54 | 1.06 | 2.13 |
| 25 m | 0.09 | 0.29 | 0.55 | 1.08 |
| 30 m | 0.06 | 0.19 | 0.33 | 0.63 |

For design purposes, the reflected over pressure can be idealized by an equivalent triangular pulse of maximum pressure \(Pr\) with duration \(t_d\) which gives the reflected pulse \(i_r\):

\[
i_r = \frac{1}{2} P_r t_d.
\]

The duration \(t_d\) is directly proportional to the time required to dissipate the pressure. The over pressure resulting from the wave reflection propagates to the edges of the obstacle at the speed of sound \((U_s)\).

If we denote the maximum distance from the edge as \(S\), then the pressure caused by the reflection is considered to be reduced from \(P_r\) to \(P_{so}\) to zero in the reaction time \(3S/U_s\).

We can assume that \(U_s\) represents the speed of sound, which is about 340 m/s, and further assume that there is a linear pressure drop after the explosion.

The pressure wave passes through the rear corner of the prismatic obstacle, the duration of which is expressed as \(5S/U_s\).

So far, the specific energy of TNT, which is 4200 kJ/kg, has been described, but the specific energy of combustion of hydrocarbon fuel (butane) is much higher and reaches the value of 46000 kJ/kg.

The internal explosion calculation is a complex mechanism that consists of two phases.

A positive element can be a glass filling, which can cut the energy level of the explosion by breaking the glass fillings.

2.3. Aerosol Explosive Mixtures

It is a matter of creating a mixture of, in particular, readily available flammable hydrocarbons, which can form explosive concentrations with air.

The fuel here does not contain an oxidizer in its molecule, and therefore cannot explode or burn without the presence of atmospheric oxygen.
Because oxygen from the environment is used for oxidation, the energy released relative to the weight of the fuel is also higher than with conventional explosives. The detonation shock wave of aerosol explosive mixtures has lower maximum pressures than conventional explosives. The shock wave propagates at a speed of 1500–3000 m.s⁻¹.

Aerosol explosive mixture has larger static and dynamic impulses, and thus is able to affect 2.7 times larger area than the same amount of a conventional explosive [29].

These are mainly gases readily available, stored in pressure cylinders such as propane-butane mixtures (LPG), natural gas (CNG), acetylene, hydrogen, etc. They can be misused to achieve an explosion by slowly mixing the gas with the ambient air. An important parameter of these substances is the explosion limit. The parameter is determined by the ratio of gas to air, which is defined by the lower and upper explosive limits.

The explosion initiation can be caused by cylinder intentional discharge, natural gas pipeline disruption in engineering networks, which result in gas accumulation in buildings.

When achieving explosion parameters, it also depends on the density of the flammable gas, the size of the environment, and the method of ventilation. A minimum amount of energy in the form of, for example, an electric spark is sufficient to initiate such an explosive mixture. The lower explosive limit represents the lowest possible concentration of a flammable substance with air at which it is still able to explode.

The upper explosive limit represents the highest possible concentration of flammable substance with air at which the mixture is capable of exploding.

The second way of misuse can be the placement of carriers (pressure cylinders) next to the booby-trapped explosive system, which in the event of an explosion due to heat or fragments will damage the flammable gas cylinder, then cause an explosion or fire.

<table>
<thead>
<tr>
<th>Explosive type</th>
<th>Used explosives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosol mixtures</td>
<td>petrol</td>
</tr>
<tr>
<td></td>
<td>propane butane</td>
</tr>
<tr>
<td></td>
<td>hydrogen</td>
</tr>
<tr>
<td>ammunition</td>
<td>Gunpowder,</td>
</tr>
<tr>
<td></td>
<td>Smokeless powder</td>
</tr>
<tr>
<td>ammonium nitrate/fuel oil</td>
<td>Ammonium nitrate + Nitromethane</td>
</tr>
<tr>
<td>ANFO</td>
<td>Ammonal</td>
</tr>
<tr>
<td>explosive</td>
<td>Acetone peroxide (triacetone triperoxide) (TATP)</td>
</tr>
<tr>
<td></td>
<td>Hexamethylene triperoxide diamine (HMTD)</td>
</tr>
<tr>
<td>nitric acid salt - explosive</td>
<td>Urea nitrate</td>
</tr>
<tr>
<td>industrial explosive</td>
<td>GOMA-2-Eco</td>
</tr>
<tr>
<td></td>
<td>Semtex</td>
</tr>
<tr>
<td>pyrotechnic compositions</td>
<td>delaborated pyrotechnics</td>
</tr>
<tr>
<td></td>
<td>Sodium chlorate with sugar</td>
</tr>
</tbody>
</table>

Gunpowder is a mechanical heterogeneous mixture of 75% potassium nitrate (oxidizer), 15% charcoal (fuel) and 10% sulfur (fuel). The gunpowder precursors are potassium nitrate, charcoal, and sulfur.

Smokeless powder has the basic components nitrocellulose and nitroglycerin. Improvised production is complicated (Table 4).

Nitrocellulose (NC) is prepared by esterification of cellulose with nitric acid and the nitration process is expressed by the equation: \( C_6H_{12}O_5 + x HNO_3 \rightarrow C_6H_{10-x}(ONO_2)_X + x H_2O \). Nitrocellulose precursors are sulfuric acid, nitric acid and cellulose.

Nitroglycerin (NG) is formed by a reaction under the action of nitric acid on glycerol, in which, depending on the reaction conditions, either glycerol mononitrate, dinitrate or trinitrate is obtained. The aim of the reaction is to obtain the maximum amount of trinitrate. In the reaction, the reaction occurs according to the following equation: \( C_3H_5(OH)_3 + 3 HNO_3 = C_3H_5(NO_2)_3 + 3 H_2O \). Nitroglycerin precursors are glycerin.

The nitration mixture consists most often of concentrated sulfuric acid (96%) and nitric acid, which, unlike NC or NG, can be considerably diluted. The concentration of nitric acid varies from 44% to 98%, depending on the production process.

Summer propane-butane mixture (40/60) and winter propane-butane mixture (60/40). Composition of C4-hydrocarbons and C2-hydrocarbons. The classification of propane-butane is F +, R12, it is an extremely flammable substance that is highly flammable.

LPG is stored under pressure in pressure vessels. When released into the space, gas reacts with atmospheric pressure, and evaporation by boiling occurs.

3. Specificity of Airport Landside Security

The Total Airport Management concept was originally introduced by DLR and Eurocontrol in 2006 and has been evolving ever since [30].
In general, any person or institution involved in or affected by the operation of an airport may be an airport entity and is:
- airport operator;
- airlines;
- air traffic control (ATC);
- ground handlers,
- security authorities or service providers as well as immigration authorities.

Therefore, all stakeholders need access to all relevant information for their operations, which means that all information must be shared by all stakeholders where possible. The growing number of passengers, especially in combination with increasing security and immigration measures, will cause serious difficulties in state-of-the-art ground processes.

The holistic improvement methods development for landside processes includes new support tools for passenger flow and the discrete resource management systems expansion.

Airport landside is defined as a terminal area and includes all passenger processes from arrival at the airport until boarding the aircraft (Table 5).

Table 5
An overview of the major processes occurring on the Total Airport Management Suite

<table>
<thead>
<tr>
<th>Airside</th>
<th>Operation Center (ATC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N operation Centres (Airlines)</td>
</tr>
<tr>
<td></td>
<td>Operation Centre (Airport)</td>
</tr>
<tr>
<td>Land side</td>
<td>Operation Centre (Airport)</td>
</tr>
<tr>
<td></td>
<td>Baggage management</td>
</tr>
<tr>
<td></td>
<td>Operation Centre (Ground Handler)</td>
</tr>
<tr>
<td></td>
<td>Cargo</td>
</tr>
<tr>
<td></td>
<td>Terminal management</td>
</tr>
<tr>
<td></td>
<td>Security management</td>
</tr>
<tr>
<td></td>
<td>Pax information and guidance</td>
</tr>
<tr>
<td>Ground Access</td>
<td>Pax information and guidance</td>
</tr>
<tr>
<td></td>
<td>Transport management centres</td>
</tr>
<tr>
<td></td>
<td>Car park</td>
</tr>
</tbody>
</table>

Airports are divided into three areas: airside, landside and the terminal itself, and ground access, which have different requirements for construction, structure, and safety.

At the same time, the airport premises are divided into security areas with different levels of access.

Airport terminals are buildings where we encounter steel structures relatively regularly. The continuous development of the check-in hall and the runway system must combine elements of safety, hygiene as well as comfort for customers.

**Brno – Tuřany**

The steel structure of the hall is composed of a structural steel vault (Fig. 3). The spatial construction of the main supporting system is made of rolled steel profiles.

The main elements are 6 arches in the transverse direction, with the height of the edging roof of 12.20 meters. The floor plan dimensions of the check-in hall are 81 × 44.5 m. The maximum length of the hall is 112 meters.

The span of the arches is 38.8 m, and the rise is 12.85 m, the radius is 21 m.

Thick-walled steel pipes TR 530 × 20 form the supporting profile of the arch.

In the longitudinal direction, the hall rigidity is ensured by two-storey reinforcing towers in both fronts of the building [31-34].

**Karlovy Vary airport** [36] The terminal construction is based on a steel arch structure with a longitudinal support system. The floor plan dimensions of the check-in hall are 70 × 28 m, and the highest bearing point is at the height of +11,200 meters. The roof is formed by TRUHL arched trusses. 300, 6, 150, 12, 50 mounted on longitudinal dies TR Ø 324 Ø 10 mm and spacing á 3,000 mm. The longitudinal radius of the roof is 161,200 mm. Wall elements are formed by a horizontal section in the upper part and an arcuate part. The center of the arches is +3,500 mm high, the radius of the arches r = 4,600 mm. The center of the arches is +3,500 mm high, the radius of the arches r = 4,600 mm. In cross-section, the main supporting arches thus form the letter V, which forms an angle of 76°. In this direction, the struts erected from the arches for supporting the longitudinal beams of the roof continue - profile TR Ø 324 × 10 mm. The spacing of the wall elements corresponds to the spacing of the roof trusses s = 3.0 m.

Both gable ends of the hall are also formed by welded boxes, however, already straight in the side view, in the shape of conic sections.

The hall rigidity in the longitudinal direction is ensured by means of frame installations in the fronts, a longitudinal frame installation, and the main arches themselves.

Anchoring of all load-bearing columns except circumferential ones is done by embedding, and circumferential anchors are articulated. [37]
4. Analysis of a Blast Loaded Steel Structure on a Steel Building

The experiments took place in January 2020 at the Ammunition Security Center - Týniště nad Orlicí. The effect of selected types of charges was measured on samples of armor or soil to investigate their true effectiveness (penetration).

TNT explosive was used as a detonation charge. Explosive charges were placed on the ground or armor. Then, five different explosives were used for the explosive load scenarios, which could be used as initiation charges (Table 6).

The characteristics of TNT are Explosive velocity 6900 m/s, heat of combustion 4200 kJ/kg, density 1.58 g/cm³, and explosive pressure 18.4 GPa.

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. TNT charge 75g, 200 g, 400 g</td>
<td>Formation of a crater in the ground</td>
</tr>
<tr>
<td>b. TNT charge 1kg, 3 kg</td>
<td>Imprint on an armor plate with a thickness of 20 mm</td>
</tr>
<tr>
<td>c. Piercing charge PN-4 (TNT/H 50/50 4,8 kg, PN 14 (TNT/H 50/50 17 kg)</td>
<td>Informatively, the depth and diameter of the crater in the soil are measured</td>
</tr>
<tr>
<td>d. Directed loaded charge UTN-2 (TNT/H 50/50 2 kg)</td>
<td>Armor penetration 75 mm</td>
</tr>
<tr>
<td>e. UTN-11 (TNT/H 50/50 10,5 kg)</td>
<td>Armor penetration 2 × 100 mm</td>
</tr>
</tbody>
</table>

The experimental program investigated one task, namely the structural behavior of the base material, a metal plate that imitated the steel pipes of the supporting elements of the terminal (Fig. 4).
4.1. Modeling of PB Explosion in the Area in Front of the Entrance to the Terminal

The case study building is a terminal measuring $81 \times 44.5$ meters and $70 \times 28$, respectively, and a height of $12.2$ meters and $11.2$ meters, respectively. The atmospheric data of the explosion site must also be taken into account in the calculation. A leak or explosion of $6/7 \text{ m}^3$ of propane-butane was calculated.

The escaping gas interaction with the ambient air has the effect of reducing the temperature, in the order of several degrees, changing the ratio of the mixture in favor of PB, and decreasing the partial pressure of water vapor.

The result of a physical gas process combination, temperature reduction, pressure drop, change in relative humidity, and PB concentration, is the visible gas cloud formation. The gas mixture cloud is, more prone to explosion at its edges, where it touches the surrounding air.

An explosion may be caused by passage through heat sources.

A cloud peripheral parts explosion will cause a change in the cloud concentration and a destructive explosion will occur (Fig. 5).

Another possibility of PB acting in the terminal space is the burning of PB by a flame. Given the distance of the front door from the side of the road, it can be assumed that if there were a fire, the fire would act for 60 seconds in three areas with different intensity and impact on human health (Table 7).

Table 7

<table>
<thead>
<tr>
<th>Distance in meters/burning intensity</th>
<th>0 - 30</th>
<th>31 - 48</th>
<th>49 - 73</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 10.0 kW/m²</td>
<td>potential death</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 5.0 kW/m²</td>
<td>2nd degree burns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2.0 kW/m²</td>
<td>pain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The model example also worked with the possibility of an explosion, which is potentially the greatest risk to the human body. Modeling the situation of an explosion of a tank or bus on LPG using the explosives tested above would initiate an explosion with a pressure wave and a lethal effect for approximately 60 seconds. A lethal pressure wave would act up to a distance of almost 200 meters (Table 8).

Table 8

<table>
<thead>
<tr>
<th>Distance in meters/burning intensity (explosion)</th>
<th>0 - 190</th>
<th>190 - 400</th>
<th>400 - 800</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 10.0 kW/m²</td>
<td>lethal effect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 5.0 kW/m²</td>
<td>2nd degree burns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2.0 kW/m²</td>
<td>pain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2. Consequences of the Effect of the Pressure Wave on the Human Body

The probability of survival of a pressure wave caused by a propane-butane explosion is calculated using the probit function.

The probit function is a statistical technique that works when evaluating the impacts of events with a probabilistic relationship between the logarithm of the size of the event dose and the response in percentage of the affected population.

The human organism is a complex system, and the action of overpressure caused by a pressure wave acts on different parts of the organism with different devastating effects (Table 9).

The results of experiments showed that the action of the physical parameters of the explosion waves has the greatest impact on the internal organs and respiratory tract, especially the lungs, which are the organ of the lower respiratory tract [41-42].
### Table 9

<table>
<thead>
<tr>
<th>Over pressure $p$ [kPa]</th>
<th>Injury description</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.8</td>
<td>Threshold value for eardrum damage</td>
</tr>
<tr>
<td>34.5 - 48.3</td>
<td>50% the likelihood of damage to the eardrums</td>
</tr>
<tr>
<td>68.9 - 103.4</td>
<td>90% the likelihood of damage to the eardrums</td>
</tr>
<tr>
<td>82.7 - 103.4</td>
<td>Threshold value for lung damage</td>
</tr>
<tr>
<td>137.9 - 172.4</td>
<td>50% probability of lung damage</td>
</tr>
<tr>
<td>206.8 - 241.3</td>
<td>90% probability of lung damage</td>
</tr>
<tr>
<td>48.3</td>
<td>Threshold for internal injuries</td>
</tr>
<tr>
<td>100</td>
<td>1% probability of death</td>
</tr>
<tr>
<td>121</td>
<td>10% probability of death</td>
</tr>
<tr>
<td>141</td>
<td>50% probability of death</td>
</tr>
<tr>
<td>176</td>
<td>90% probability of death</td>
</tr>
<tr>
<td>200</td>
<td>100% probability of death</td>
</tr>
</tbody>
</table>

### 5. Conclusion

The relationship between the structural safety of buildings in the landside and airside areas and the effects of accidental explosions or terrorist explosions is constantly in the attention of all stakeholders.

Buildings on the airport city premises must take measures to eliminate risks, including the elimination of mobile equipment, while achieving the required level of passenger comfort.

Modern building technologies and the availability of explosive materials, or its domestic production, are stimuli to think about when designing new urban approaches.

Due to the modern urban airport city concept, in the security area, possible solutions are offered for the mobile devices detachments, which can potentially be devices usable for attacking CI objects to a more distant perimeter of the airport.

The gas explosion impact depends on the epicenter of the explosion distance.

The operation of a full-service airport is a direct, indirect, and inducing stimulus to economic growth.

It creates jobs in all provided services and indirectly supports the development of supply chain management. Another economic factor is the support of other sectors of the economy.

The urban concept of a modern airport will respond to the solution of time-consuming activities. There is an obvious effort to eliminate waiting at the airport, the check-in process, and security procedures at the terminal. Bottlenecks elimination is a biggest obstacle to passenger comfort.

The implementation of new technologies and a new urban concept of the airport city will lead to streamlining processes. New technologies will allow passengers to move around the airport, eliminating current obstacles.

The use of biometric authentication and the means of a security system will enable continuous movement in the airport.

The introduction of biometric tracking of persons must be followed by changes in airport security handling. New biometric technologies will require a change in the security control scheme in all areas of the airport.

Airport security management will work with a new architecture that will include a wider perimeter of the airport. Biometric scanning will make it possible to transfer controls to the outer perimeter of the airport, at the site of transport terminals.

The continuity of passenger movement, invisible services, and the flow of material requires the design of spaces where people are supposed to gather.

The basic proposed elements will include the arrival hall, departure hall, security zone, and logistics. Airports remain the gateway to the country, and the airport's spatial planning will be a link for the city's infrastructure and the wider environment. The aim is to create integrated centers with good transport infrastructure and services, where green development will be accepted.

### Reference

Analysis of Long-Term and Maintenance Parameters and Their Impact on Degradation of UAV Accumulators

V. Ažaltovič1, I. Škvareková2, B. Kandera3

1 Air Transport Department, University of Zilina, 010 26, Zilina, Slovakia, E-mail: viliam.azaltovic@fpedas.uniza.sk
2 Air Transport Department, University of Zilina, 010 26, Zilina, Slovakia, E-mail: iveta.skvarekova@fpedas.uniza.sk
3 Air Transport Department, University of Zilina, 010 26, Zilina, Slovakia, E-mail: kandera@fpedas.uniza.sk

Abstract

Unmanned Aerial Vehicles are complex systems which are dependent on electric energy, since they contain a lot of devices, equipment and payload used during the execution of the mission. Storing the electric energy directly onboard can be done through the electric energy storage equipment, such as lithium polymer accumulators. The main goal of this paper is an analysis of lithium polymer accumulators with different levels of usage and its impact on capacity and further serviceability of the accumulators. The study was performed by a complex analysis of 57 samples of lithium polymer accumulators. Degradation of each accumulator was evaluated from two points of view, the number of cycles, and the age of the individual accumulator. The results of the article show different values from analyzed points of view.

KEY WORDS: Lithium Polymer Accumulators, UAV, degradation, capacity, Li-Po

1. Introduction

Using rechargeable accumulators, such as Lithium Polymer or Lithium Ion, has been a popular method for storing electrical energy since the 1990s, when these batteries were introduced. Since then, lithium polymer accumulators can be found in a wide spectrum of energy-dependent products, such as mobile phones, laptops, hybrid cars and Unmanned Aerial Vehicles. Lithium Polymer accumulators gained their name for using a polymer electrolyte instead of liquid electrolyte. [1, 5, 6, 10, 11]

As usually, each type of accumulator has its advantages and disadvantages. Those are key pros and cons of Li-Po batteries (Fig. 1) [10, 12].

Advantages:
• Variable shapes and sizes;
• High energy density;
• Relatively low rate of self-discharge (about 5% a month);
• Large power capacities.

Disadvantages:
• Higher risk of explosion than other accumulators;
• Possible expansion due to short circuit failure;
• Requires special charger stations;
• More expensive than other similar accumulators.

The nominal value of Li-Po accumulators is set on 3.7 V, which is the average voltage at 50% discharge depth. The highest possible voltage of Li-Po accumulator is approximately 4.4 V and the lowest possible voltage, before the battery will be temporarily damaged is 3.0 V.
Table 1
Comparison of different storage types based on specific energy and energy density [10]

<table>
<thead>
<tr>
<th>Storage type</th>
<th>Specific energy [MJ/kg]</th>
<th>Energy density [MJ/L]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-Po battery</td>
<td>0.36 – 0.95</td>
<td>0.90 – 2.63</td>
</tr>
<tr>
<td>Diesel</td>
<td>45.6</td>
<td>38.6</td>
</tr>
<tr>
<td>Jet A</td>
<td>43.02</td>
<td>35.3</td>
</tr>
<tr>
<td>Gasoline</td>
<td>46.4</td>
<td>34.2</td>
</tr>
<tr>
<td>Liquid Hydrogen</td>
<td>119.93 – 141.86</td>
<td>8.491 - 10.044</td>
</tr>
</tbody>
</table>

As can be seen from Table 1, Li-Po accumulators reach in the means of specific energy and energy density significantly lower than other chosen storage types, approximately by 50. These two indicators are extremely important in the energy assessment:
- The specific energy or mass energy means the energy per mass unit;
- Energy density is the amount of energy stored in a given system or region of space per unit volume.

Energy density is sometimes useful for comparing fuels. For example, liquid hydrogen fuel has higher specific energy (energy per unit mass) than gasoline does, but a much lower volumetric energy density [10].

According to the few producers of Li-Po accumulators, the lifespan of these batteries may vary. The number of cycles can range from 300 to 500 cycles. The lifespan depends on the charging C-Rate. 500 cycles are possible to achieve when the 0.5 C rate is used during the charging, while 300 cycles the battery is possible to achieve when the 1 C rate is used during charging. The lifespan could be defined also by the loss of capacity, which is set on 20% of loss of capacity. The last way to determine the lifespan of the accumulator is the age, which is not fixed. Some of the manufacturers recommend using the accumulator no longer than 4 years, others recommend using them no longer than 8 years.

In the sector of UAVs, sources of energy placed directly onboard are strategically necessary [2, 4]. UAVs can be categorized into 3 groups: with moving on surfaces producing buoyancy, multi-copters or planes [7]. Depending on the use of UAV, it can be either fully electric including propulsion system and, or source of power for payload [3, 8], or it can be only partly powered by electric energy from lithium polymer sources.

2. Safety

Manipulation with Li-Po batteries can be dangerous since they undergo the chemical processes. During any kind of hazardous manipulation with Li-Po batteries, such as charging or discharging, is important to use equipment that ensures the highest possible safety [6].

For LiPo battery packs with cells connected in series, a specialized charger may monitor the charge on a per-cell basis so that all cells are brought to the same state of charge (SOC).

It is necessary to use a charger with (Fig. 2):
- balancer, so each cell is charged separately and;
- charging options, so it is possible to set the right charging current for each accumulator.

![Fig. 2 LiPo-Safe charging bag [7]](image)

3. Materials and Methods

All measured accumulators were initially in the so-called storage mode. The storage mode is the state of the accumulator when the user knows, he will not use the accumulator for a longer period of time. In this mode, the accumulators are charged to 60% of their capacity. During the measurement, all accumulators were charged to 100%, then discharged to approximately 20% of their capacity - which is the minimum possible capacity before permanent damage. After the accumulators were discharged, the values from the charging station were written down. Then, the accumulators were charged to the full capacity and values were written down again. Despite different capacities and other accumulators’ characteristics, all lithium-polymer cells were discharged and charged under the same conditions. All of them were discharged and charged afterward with a 1C rate. This cycle was also included in the statistics. To ensure that the measured values and results are relevant, all batteries were charged and discharged on the same charger while using the balancer.
The charge and discharge rates of a battery are governed by C-rates. The capacity of a battery is commonly rated at 1C, meaning that a fully charged battery rated at 1Ah should provide 1A for one hour. The same battery discharging at 0.5C should provide 500mA for two hours, and at 2C it delivers 2A for 30 minutes. Losses at fast discharges reduce the discharge time and these losses also affect charge times.

A frequency distribution is a representation, either in a graphical or tabular format, that displays the number of observations within a given interval. The interval size depends on the data being analyzed and the goals of the analyst [9]. The intervals must be mutually exclusive and exhaustive. This is what we have done in our case as well. As can be seen, the Fig. 3 is divided by an interval of 22, which represents the number of cycles, and in Fig. 4 is divided by interval 9, which represents the age of the Lithium Polymer battery.

Frequency distributions are typically used within a statistical context. Generally, frequency distribution can be associated with the charting of a normal distribution.

All measured batteries were summed up to the table and the most important data of batteries were listed in Table 2. Since the analysis was performed on 57 Li-Po batteries with different capacities, a number of cells and age, the table is very comprehensive, so Table 2 is the only a sample, how the table looked like.

<table>
<thead>
<tr>
<th>Sample table</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity by manufacturer [mAh]</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>13</td>
</tr>
</tbody>
</table>

As can be seen, any kind of information about the manufacturer of each accumulator is missing. This was done on purpose, because the authors are trying to avoid the manufacturer’s preference based on the study results.

4. Results

Results from complex analysis were summarized in Fig. 3 and Fig. 4.

![Fig. 3](image-url) Dependence of the number of cycles and the average percentage capacity loss

Fig. 3 represents the dependence of the number of cycles and the average percentage of capacity loss. As can be seen, the interval of 205 – 227 cycles indicates the second highest value of the accumulator degradation according to the number of cycles, despite the fact, that this value is only in the fourth place in the figure. This is caused by most likely badly produced accumulator, because the average percentage capacity lost has reached more than 45%. To keep this
study relevant, the authors have decided not to take into account those batteries. The interval of 294 - 319 is empty due to the absence of battery with the number of cycles in this interval.

Fig. 4 Dependence of the age of batteries and the average percentage capacity loss

5. Conclusions

The article shows up, the operational characteristics of lithium-polymer batteries from two points of view, the number of cycles, and age of individual batteries. During the study, the authors have been working with 57 lithium polymer accumulators, which have been in real operational conditions for a wide range of operating time.

The results of the measurements show that the age is a key factor, since the values in Figure 4 have appeared to have an increasing tendency. On the other hand, the results have shown, that even the exceeding the recommended number of cycles stated by manufacturers and charging the accumulators with 1C rate is not causing that much degradation as the age of the accumulator itself. This can be visible in Figure 3, where values in the last interval of 87 – 96 months exceed the acceptable level of degradation – which is stated to be 20% of loss of capacity.

On the other hand, values in Figure 3 have not confirmed, that number of cycles has an as significant an impact on degradation as the age of accumulator, since the curve of this figure has a sinusoidal character. This can be caused either by a low number of samples, or a high level of degradation of accumulators in selected intervals.

The article provides basic data but also serves as a stepping-stone for further research in the field of accumulators for UAV and could serve for creating a uniform standardization for using, not only lithium polymer accumulators, but accumulators in global for increasing operational safety of UAVs. This is the key factor for increasing the safety of the operation of unmanned aerial vehicles in the airspace, as we know, that usage of those vehicles in the last few years is increasing.

References

10. Üçgün, H.; Yüzgeç, U.; et al. 2019. The Comparison of Energy Sources Used in Unmanned Air Vehicles. DOI: 10.7176/JSTR/5-6-05
Design of the Air Velocity Measuring Inlet Channel for the Small Jet Engine

J. Čerňan¹, F. Škultéty²

¹University of Zilina, Faculty of Operation and Economics of Transport and Communications, Department of Air Transport, Univerzitná 8216/1, 010 26, Žilina, Slovakia, E-mail: jozef.cernan@fpedas.uniza.sk
²University of Zilina, Faculty of Operation and Economics of Transport and Communications, Department of Air Transport, Univerzitná 8216/1, 010 26, Žilina, Slovakia, E-mail: filip.skultety@fpedas.uniza.sk

Abstract

This article deals with the process of designing of the air duct, capable of measuring the velocity of air flow entering the small jet engine JetCat 200. This engine is primarily used for educational purposes at the University of Zilina, and generally for propelling flying aircraft models. The JetCat200 is a small but powerful jet engine that can fly at very high speeds, but in the educational process, there is a need for students to be familiar with all its operational parameters and restrictions. The aim of this study was to design the air duct, able to sense the air pressure changes of air flow and according to these changes to measure the air velocity at the entrance to a jet engine. This will help by deeper identification of mass flow and thermodynamic processes inside the engine. After the process of manufacture of designed Venturi tube duct by 3D printer, followed preparation for testing measurements. During these tests were a classical pitot-static tube used for comparison of air velocity measured data. Results show a very good level of conformity in measured values.

KEY WORDS: Venturi tube, pitot-static tube, air velocity, jet engine

1. Introduction

Each jet engine inlet device must ensure the correct operation of the aircraft propulsion unit at all aircraft positions, in all phases of flight and any engine mode [1].

From the operational point of view, the inlet device is an integral part of the engine. The basic function of the inlet device is to supply the required amount of air to the compressor. Any inefficiency of the input device will cause pressure losses to increase, which will affect the work of other parts of the engine [2]. Pressure losses occur precisely when passing through the inlet device by friction against its surface, as well as by changes in the direction of flow.

Direct airflow keeps turbulence to a minimum as it does at the inlet. The inlet device first has a widening cross-section, which ensures a deceleration of the flow, and thus an increase in static pressure in front of the compressor face. Some entrance devices are equipped with automatic intake doors, which can supply additional air to the duct for take-off mode during take-off and during flight at low speeds [3].

Several systems and measuring devices are used to measure air velocity and its mass flow rate. Each system is designed for one separate partition. Handheld anemometers, registration mechanical anemographs, registration digital anemographs and thermoanemometers are used to measure wind speed. For aviation, a pitot tube or a pitot-static tube is mainly used to measure air speed [4, 5].

In this study we focus mainly on the air flow in the input device and the design of the measuring duct in front of the input device. This measuring duct is based on the Venturi tube principle. The Venturi tube function is very well described by the Bernoulli equation and the Continuity equation. Using these equations, we can numerically evaluate the air flow velocity in a given tube according to pressure change, i.e. we can determine also the mass flow of the current air entering the input device.

For measuring the air velocity we can use knowledge of aerodynamic flow. The velocity measurement thus works on the principle of the measured pressure in one part of the Venturi tube (narrower part) – Fig. 1, and subsequently its comparison with another measured pressure in another part of the Venturi tube (wider part). According to Bernoulli's equation, the pressure of the flowing fluid decreases with increasing velocity. This equation gives us an indirect measurement of velocity. In order to be able to correctly determine and evaluate the required velocity, we need to use the Continuity equation. The Continuity equation explains the flow in a narrowed or enlarged diameter. In this case, it will be in a narrowed diameter, where there is an acceleration of the air flowing through the measuring duct [6, 7].

Bernoulli's equation [6]:

\[ p + \frac{1}{2} \cdot \rho \cdot v^2 = \text{const} \]  

where \( p \) – supplied pressure; \( \rho \) – density of air; \( v \) – velocity of air flow.

Continuity equation [6]:

\[ \frac{1}{2} \cdot \rho \cdot v_1^2 < \frac{1}{2} \cdot \rho \cdot v_2^2 \]  

where \( v_1 \) – velocity of air flow in the wider cross-section of the tube; \( v_2 \) – velocity of air flow in the narrower cross-section of the tube.
where \( v_D \) – supplied velocity of air in the wide part of Venturi’s tube; \( v_d \) – supplied velocity of air in a narrow part of Venturi’s tube; \( S_D \) – an area of the wide part of Venturi’s tube; \( S_d \) – the area of the narrow and wide part of Venturi’s tube; \( v_D \) – velocity of air flow in the wide part of Venturi’s tube; \( v_d \) – velocity of air flow in a narrow part of Venturi’s tube; 
\( \pi \) – Ludolf’s constant; \( D \) – diameter of the wide part of Venturi’s tube, \( d \) – diameter of the narrow part of Venturi’s tube.

By combining these two formulas we can express the air flow velocity. We will discuss the mentioned equations in more detail and the expression of speed calculations in the next chapters.

Probes for measuring velocity on aircraft, working on the principles of Bernoulli’s equation and continuity equation, can be performed as a Venturi’s or a pitot-static tube – Fig. 2. The probes measure the flowing air using the required holes and, using a pressure gauge box based on these equations, value is expressed that shows the required value. Sensing and measurement of air velocity, as well as total pressure and static pressure is carried out mainly by means of pitot or static tube, or their combination pitot - static tube. Pitot-static tube has a suitable aerodynamic shape, which is specially modified holes, from the front of the tube or on its sides. There is one hole on the front of the pitot-static tube, which is used to sense the total pressure. On the sides of this tube, holes are located in a suitable place for sensing static pressure. The pressure values from the inlet openings (total and static pressure) are suitably fed into the pressure measuring boxes [8, 9].

2. Measuring Air Duct Design

The design of the measuring air duct for a small jet engine was designed using the CAD CREO 5.0 software, then printed on a 3D printer. After the 3D printer, the surface of the measuring track was not ideal, it was necessary to physically treat it with sandpaper and then spray it to smooth and level the surface of the measuring track.

The design of a measuring air tract for a small jet engine using a Venturi tube to measure the air parameters in this tract is based on the Venturi tube principle. The air measuring tract is designed for a small JetCat200 jet engine. The measuring tract must have a suitable aerodynamic shape to guarantee the best possible flow with the least possible resistance – Figs. 3-5. There are measuring holes on the tube to measure the flowing air and must be positioned correctly to ensure sufficient pressure sensing. These openings are located at the beginning, in the middle at the narrowest point and the end of the air measuring tract assembled in Fig. 6. After flowing through the measuring points, the air is then led into a closed arc, from which it then continues through the outlet to other parts.

It is necessary that the measuring duct has a suitably modified overall shape and its final part should be shaped so that it can be suitably mounted on the input device of a small jet engine JetCat 200. In addition to the air measuring
tract, which will measure the velocity of the flowing air and the mass flow, it is important to add a small pitot-static tube, which performs the calibration and determines its accuracy. To find out the correct data, we will use a small pressure gauge box, into which air will be supplied from the pitot-static tube or from the measuring tract by means of hoses. The pressure measuring box compares the pressure flowing through the air measuring tract, or the pressure flowing through the pitot-static tube, which then electronically transmits the sensed pressure values to the printed circuit board. The printed circuit board must be programmed correctly to be able to convert all the sensed pressure values into velocity values. The programmed printed circuit board must guarantee the display of the scanned values in certain devices by means of a USB cable, most often in a computer display or on a digital display [10].

Fig. 5 Last part of measuring air duct

Fig. 6 Final assembly of measuring air duct

After manufacturing by 3D printer, using ABS plastic material, were all parts of the measuring air duct connected by bolts and installed on the jet engines as showed in Fig. 7. After this installation follows the connection of 3 rubber hoses for transferring pressure changes into the pressure sensors. This sensor was at first connected to pitot-static velocity probe for test measuring because of the comparison these two devices. The pressure sensor is by wires connected to the Arduino circuit microcontroller board, which is responsible for real-time calculation of air flow velocity as documents Fig. 8.

Fig. 7 Installation of measuring air duct on jet engine

Fig. 8 Final assembly of measuring device – pitot-static tube with Arduino microcontroller

3. Experiments

The first of the test experiments were performed by the use of a table fan and conventional pitot-static tube. This fan has two speed settings. The measuring duct is exposed to both air velocities performed by a fan, which we recorded in Table 1. After measuring several values, we also exposed these same velocity settings to our designed Venturi’s type tube. As the measurements were made in an enclosed space, the air flow was not affected by any other influences.

The velocity values in the following table are expressed in meters per second. According to the table, we can see the accuracy by comparing the values from the measuring tract and the values from the pitot of the static tube.

The second experiment was performed on a moving car, using cruise control and a remote road where this measurement could be safely performed. The oncoming car on cruise control had a set speed of 60 km/h, 80 km/h and 100 km/h. The Venturi’s type measuring duct as well as the pitot-static tube were exposed to the oncoming air outside of the car. However, as the experiment was performed in an open environment, this measurement could be affected by outdoor weather, rain, wind and the angle of holding the Venturi’s air velocity measuring duct.

The values in the following Table 2 are also expressed in meters per second. In addition to the possibility of comparing the measuring duct with a pitot-static tube, there is also the possibility to compare the measuring duct with the car speed meter at a given speed and with the correct transfer from the meters per second to kilometers per hour.

After the correction in program velocity calculation uploaded into the Arduino microcontroller could be possible to perform a third test on the jet engine.

The third experiment of a Venturi’s measuring air duct connected to a small JetCat200 jet engine was not performed due to maintenance performed on the jet engine. However, it is suggested that this experiment be performed in the near future or for further studies.
### Table 1

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Venturi’s type duct</th>
<th>Pito-static tube</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Velocity setting No. 1</td>
<td>Velocity setting No. 2</td>
</tr>
<tr>
<td>1</td>
<td>3,49</td>
<td>4,08</td>
</tr>
<tr>
<td>2</td>
<td>3,55</td>
<td>4,02</td>
</tr>
<tr>
<td>3</td>
<td>3,60</td>
<td>4,18</td>
</tr>
<tr>
<td>4</td>
<td>3,49</td>
<td>4,37</td>
</tr>
<tr>
<td>5</td>
<td>3,49</td>
<td>4,46</td>
</tr>
<tr>
<td>6</td>
<td>3,50</td>
<td>4,51</td>
</tr>
<tr>
<td>Average value</td>
<td>3,52</td>
<td>4,33</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Venturi’s type duct</th>
<th>Pito-static tube</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 km/h</td>
<td>80 km/h</td>
</tr>
<tr>
<td>1</td>
<td>14,39</td>
<td>17,37</td>
</tr>
<tr>
<td>2</td>
<td>14,75</td>
<td>18,36</td>
</tr>
<tr>
<td>3</td>
<td>14,29</td>
<td>18,33</td>
</tr>
<tr>
<td>4</td>
<td>13,64</td>
<td>17,71</td>
</tr>
<tr>
<td>5</td>
<td>13,77</td>
<td>17,94</td>
</tr>
<tr>
<td>6</td>
<td>14,44</td>
<td>17,27</td>
</tr>
<tr>
<td>Average value</td>
<td>14,21</td>
<td>17,83</td>
</tr>
</tbody>
</table>

### 4. Conclusions

The inlet device has to be measured geometrically in detail, as the air velocity measuring tract is designed just for the inlet device of a small jet engine JetCat 200. It was also necessary to perform calculations and point out which equations are related to the input device and also to the velocity measurement.

To measure the velocity, we have to design the shape of the Venturi’s tube, which was designed using a CREO software and a 3D printer. We tried to point out the created design and then perform an experiment on it.

It was on this issue that we focused on two types of experiments, the result of which was to determine the accuracy of the measuring duct. We determined this accuracy using a pitot-static tube, which was exposed to the same measuring factor as the measuring duct itself.

By measurement, we conclude that the proposed air velocity measuring duct is quite accurate from the average of measured values, but its deviation is approximately a multiple of 1.25 m/s. With the pitot-static tube, we found that the measurement of values on the fan at low speeds is not accurate, as the pitot-static tube was not able to measure the appropriate values.

### Acknowledgements

Authors would like to thanks for financial support from KEGA č. 034ŽU-4/2020.

### References

The Impact of Training Organization on the Effectiveness of Training in Spatial Disorientation

D. Bogusz

Military University of Aviation, Dywizjonu 303 no 35, Dęblin, Poland, E-mail: d.bogusz@law.mil.pl

Abstract

The article describes the organization of training on a spatial disorientation simulator. Particular attention was paid to the role of training organization in achieving training goals when using modern simulators. Modern training tools without the proper organization of classes and detailed methodology for conducting them will not ensure efficient implementation of flight training.

KEY WORDS: simulator, flight training methodology, organization of flight training

1. Introduction

Flying is a very dangerous kind of human activity. Military pilots piloting an aircraft operates in an environment to which they were not adapted by nature in the process of evolution. This leads to numerous threats causing accidents and disasters. Ensuring safety and efficiency in aviation training should always be a priority. Achieving these goals is possible thanks to the use of simulators in the training. Simulators are important tools which enable high results in training and improving aviation skills.

In the process of aviation training for military pilots and other aviation personnel, it is difficult to imagine training without the use of modern equipment. Despite the technical development and the use of modern simulators, the most important role in the flight training process plays the human, as well as the proper organization of the training process.

Basic research shows that by using flight simulators, high training effects can be achieved while significantly reducing training costs [3]. Training on simulators allows the pilot to develop habits of carrying out difficult tasks in the air. In some cases, e.g. the occurrence of the phenomenon of spatial disorientation, only simulators provide pilot training while maintaining safety training standards. Training using the spatial disorientation (SD) simulator (Fig. 1) is the only method for learning how to deal with the phenomenon of loss of spatial orientation by pilots without the risk of a catastrophe or an air accident [1].

Fig. 1 General view of spatial disorientation (SD) simulator

The aim of the article is to describe the training organization of the course which goal is to improve the military pilots' knowledge of the spatial disorientation and the main stages of this training. The author focuses on solving the problem - does the proper organization of the training process on the spatial disorientation simulator of military pilots enable effective and safe training during SD phenomenon? It seems that this is possible thanks to the introduction of a spatial disorientation simulator (SD) into the aviation training together with the developed methodology of this training.

Many factors influence the effectiveness of training on the spatial disorientation simulator. The basic conditions for effective training include organizational factors.

2. Conditions for Effective Flight Training

Aviation training organisation has a major impact on efficiency. The selection of the appropriate training method
and the order of the individual stages allows achieving the training objectives and a high level of security.

The methodology of flight training is a set of various rules, methods and measures aimed at providing the candidate with the pilot specific messages and developing the necessary skills and habits [5]. Simulator training is aviation training, it follows the principles used in practical training conducted in the air.

The basic areas conditioning the proper implementation of flight crew training are training base, instructor staff, training programs, and methodology for conducting theoretical classes, simulator and practical training [4] (Fig. 2).

![Fig. 2 The basic conditions for the proper implementation of the training](image)

The aviation organization should have a highly qualified instructor staff presenting a high level of experienced specialists prepared to implement the full training process, according to the center's training qualifications. The instructor should stay on purpose and organized prepared to conduct this type of training. It is unacceptable for instructors, when undertaking such classes, to adopt the method of their implementation known from their own experience. They should enrich their didactic workshop with modern methods, forms and teaching techniques. After introducing modern equipment to training, it is a must to apply patterns appropriate to a modern flight training system. It is not enough to be an observer of others to be able to conduct classes in a methodical way that guarantees the achievement of the training goals. Therefore, managers of flight training centers should pay special attention to the proper selection of instructors conducting classes in theoretical, simulator and practical training [4].

The success of flight training depends on the instructor's impact on trainee. The instructor must be a master at the piloting technique, can transfer his knowledge and skills to the trainees, have theoretical knowledge, good psychophysical conditions and high moral qualities.

To achieve the main training objectives, the **training base** should be adapted to the nature of the training activities carried out. The essential elements of the training base necessary for effective aviation training are, primarily, **practical training equipment** - it is advisable for each aviation organization to have the full spectrum of aviation equipment necessary to carry out the tasks specified in the organization's certificate.

**Training simulators and flight simulators** are the basic devices supporting the flight training process. They are part of the training base and cover three main areas, i.e.:

- **theoretical training** - when a simulator is used as a synthetic training tool allowing to demonstrate the principles of operation, construction and operation and the use of a number of aircraft equipment and systems - e.g. instruments and radio-navigation systems;
- **simulator training** - when the flying trainer is used for the practical implementation of training exercises in the field specified in the training program;
- **practical training in the air** – when the flight simulator is treated as a device that allows you to practice all elements related to realisation of the planned task. Wanting to take full advantage of the benefits from the use of training simulators and flight simulators in the flight training process, each flight training center should have these devices to an unlimited extent.

The next element of the training base is **classrooms and workshop rooms (laboratories)** enabling the implementation of classes defined in theoretical and improvement training content as part of lectures, exercises, laboratories, workshop classes, including computer rooms and language laboratories. Together with **tools and devices supporting the theoretical training process** that enables visualization of the transmitted content (projectors, computer sets). Specialized computer programs allow the transfer and recordings of the programs' content. School laboratory sets allow explaining the basic laws and phenomena occurring during aircraft movement in the airspace, the principle of operation of specific aircraft devices and aircraft systems [4].

Training programs used by aviation organizations are another factor that has a major impact on the quality of flight training. In accordance with applicable regulations, each aviation organization should have a theoretical, simulator and practical training programs in place to achieve its training objectives. Regardless of the level of the training, program authors should be guided by a number of rules applicable to the creation of such programs.

The training methodology describes the organization of training during the loss of spatial orientation and determines the tools used in this regard. Areas of responsibility at particular levels in the training process were specified and requirements for input and output data for individual levels and units involved in the training were defined. The methodology defines the method of training the flying personnel on the spatial disorientation simulator at the Military University of Aviation in Deblin.

### 3. The Role of Functionaries in SD Training

In order to secure and efficiently implement the training on the courses of improving spatial disorientation, functional persons responsible for efficient conducting of classes were appointed. Determining the necessary scope of work for people involved in the training is a condition for achieving the training objectives. The overall tasks were divided into tasks and specific activities for individual people involved in the implementation of the course of improving spatial
disorientation to organize the training process and ensure coordination of activities and resources (Table 1).

### Functional persons and the scope of their duties

<table>
<thead>
<tr>
<th>Function</th>
<th>Main tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILOT - INSTRUCTOR</td>
<td>• supervision over the correct course of the flight &lt;br&gt;• observation of the pilot's behaviour at stages of the mission &lt;br&gt;• introducing (provoking) behaviours conducive to the phenomenon of spatial disorientation in the trainee &lt;br&gt;• keeping simulator training documentation &lt;br&gt;• assessment of the correctness of the response to situations which arose during the practical training &lt;br&gt;• discussion of the task (mission) as a form of preparation for the flight and review after the flight</td>
</tr>
<tr>
<td>DOCTOR</td>
<td>• pilot-student examination before training in the scope corresponding to the pre-flight examination &lt;br&gt;• technical and medical preparation of the trainee (setting up devices for recording medical parameters) &lt;br&gt;• adjudicating on the inability to undergo training &lt;br&gt;• supervision for training on one's responsibility &lt;br&gt;• monitoring the medical parameters indications</td>
</tr>
<tr>
<td>SECURITY ENGINEER</td>
<td>• maintaining technical efficiency of simulator devices &lt;br&gt;• supervision over the correctness of all parameters registered during the training &lt;br&gt;• supervision and operation of the simulator in accordance with a user manual &lt;br&gt;• preparing the simulator for training &lt;br&gt;• providing service during training &lt;br&gt;• participation and conducting theoretical training in the extent of their responsibility &lt;br&gt;• keeping operational documentation</td>
</tr>
</tbody>
</table>

Source: Own elaboration based on the methodology of a spatial disorientation simulator training

The most important person in spatial disorientation training (in addition to the trainee) is the pilot-instructor who is the simulator operator and he/she mainly decides about the course and scenarios implemented during the training. The instructor bears full responsibility for the SD simulator training and the training methodology. The training doctor is responsible for admitting and preparing the trainee for training and he/she supervises the course of the exercise. The security engineer is responsible for the technical preparation of the SD simulator which needs to be done each time before the training begins. The preparation includes adapting the SD simulator cab to the appropriate model of the type of aircraft (jet aircraft, transport aircraft, helicopter) and checking its technical condition.

Each functional person appointed to carry out the training bears responsibility in the designated scope described in the *Methodology of Conducting Training on the Spatial Disorientation Simulator*.

### 4. Stages of Training in Spatial Disorientation

A characteristic feature of aviation training is its stage nature. Stages of training constitute one whole and interpenetrate each other. At each stage, due to the objectives of the training, different aviation equipment, flight programs are to be used. The problem is the use of teaching aids, content and such arrangement of the training program that would allow a smooth transition from stage to stage. In order to ensure an adequate level of training quality on the spatial disorientation simulator, training was divided into five main stages (Fig. 3). Below is an algorithm illustrating the "path" of the student-pilot. It comprehensively covers the organization of the training process in spatial disorientation [2].

![Fig. 3 Stages of the spatial disorientation perfecting course](image)

**Research** ➔ **Theoretical training** ➔ **Anticipation** ➔ **Practical training** ➔ **Analysis and evaluation**

**Practical training** is an essential part of training on an SD simulator. It allows the pilot to have a thorough understanding of the state of spatial disorientation that may occur during a flight. Practical training is carried out on the SD simulator after passing the two preceding stages, i.e. medical examination and theoretical training.

Before the task (training mission), each participant performs an instructional flight to familiarize the pilot with the ergonomics of the cabin and pilot characteristics of the SD simulator for a given type of aircraft. This is to develop muscle memory (SD pilot characteristics) at the required level, which will minimize the negative impact of the lack of motor skills on the training and training process (research). The instructional flight is carried out without introducing confusion...
factors (platform flight, etc.)

An instructional flight for a jet and transport aircraft module includes:
- start, ascent;
- horizontal flight;
- ascending and shaft flight;
- turns with fixed tilt 45, 60-70;
- maneuvering speed in smooth and landing configuration;
- procedural approach to landing.

The elements performed by the student during the instructional flight are assessed by the pilot-instructor. If a student fails to carry out an instructional flight or performs it incorrectly, in justified circumstances the instructor-pilot may allow it to be repeated once. A positive assessment of the implementation of the instructional task allows you to start the next stage of practical training, i.e. training mission. Incorrect completion of the second instructional mission equals not allowing the student to continue training, therefore ending his/her training. The instructional flight is to be taken in atmospheric conditions without visibility of the natural horizon [2].

To avoid mission repetition, training mission sets were developed in a group of trained students. These are included in the programs of air missions favoring the loss of spatial orientation for jet, transport and helicopters. The resources of air missions accumulated in the programs are large enough to provide a different set of tasks to be performed for each participant.

With a view to conduct training covering all possible flight conditions, scenarios for spatial disorientation were developed for each of the following categories:
1. Aviation missions carried out in VMC (visual meteorological conditions) in D/N (day/night);
2. Aviation missions carried out in IMC IMC (instrument meteorological conditions) in D/N (day/night).

The choice of mission for the D/N practical training plan depends on the student's experience (flight time) and the type of training in spatial disorientation (basic or improving).

To induce a state of spatial disorientation during a flight, depending on the type of confusion intended to be induced, the pilot-instructor interferes with the correct course of the flight (in its various phases). The distraction of the student from the current activities in the cabin can be achieved by taking the following actions by the instructor-pilot:
- additional radio commands to perform the actions specified by the pilot (changing the radio channel, visually checking the door closing, long-term observation of cockpit instruments, etc.);
- sequential deactivation of navigation devices;
- change of projection of atmospheric conditions without notice;
- putting the SD simulator's cabin into rotation during the maneuver.

Two types of excitations may be used simultaneously. As the basic variant of the projection of excitations, their occurrence is assumed in the following flight stages (Fig. 4):
1. after 4-5 min. from the start (during procedural departure);
2. during pilot maneuvers;
3. during the procedural approach to landing (during maneuvers changing the magnetic course to capture the descent path and flight altitude) [2].

Depending on the course of training, the pilot-instructor can, at any time during the training mission, initiate exertion to achieve the occurrence of any type of confusion.

5. Security Conditions

Conducting training on the spatial disorientation simulator is carried out in accordance with generally applicable
implementing, took actions in the design and ergonomics of the SD simulator and in the organization of training (Table 2).

Detailed health and safety regulations in the field of practical training and operation of the SD simulator are specified in the Health and Safety Instruction in the workplace - SD Simulator - at the training center.

Taking into account the specificity of training, i.e. the potentially higher risk of students' upset during the practical part of the training, in order to ensure the safe conduct of training, both the simulator manufacturer and the training center implementing, took actions in the design and ergonomics of the SD simulator and in the organization of training (Table 2).

<table>
<thead>
<tr>
<th>In terms of design solutions and ergonomics:</th>
<th>In the terms of training organization:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- application of SD simulator design solutions which ensure the safety of operating personnel;</td>
<td>- only persons with appropriate training and familiarization with the detailed health and safety instructions are allowed to use and train;</td>
</tr>
<tr>
<td>- the simulator design enables quick evacuation of students in a case of hazard;</td>
<td>- all training participants are subject to constant medical supervision by the physician supervising the training;</td>
</tr>
<tr>
<td>- if the simulator cab door is opened, the simulator (dynamic stand) is immediately stopped (immobilized);</td>
<td>- in the case of an emergency shutdown of the SD simulator (automatical or manual), its restart is possible after explaining and removing the causes causing its deactivation;</td>
</tr>
<tr>
<td>- the simulator's cabin door can be opened from inside and outside;</td>
<td>- before practical training, the student is familiarized with the symptoms of simulator disease and encouraged to report them if they occur;</td>
</tr>
<tr>
<td>- non-combustible or self-extinguishing materials were used in the construction of simulator components, so no toxic substances would secrete.;</td>
<td>- in a case of symptoms of a simulator disease, the student stops training and is provided with medical assistance [13];</td>
</tr>
<tr>
<td>- power switches and emergency handles are located in easily accessible places;</td>
<td>- a student is not allowed to train if he has done a real flight on that day;</td>
</tr>
<tr>
<td>- the simulator is equipped with an emergency power supply system for electronic systems enabling safe end of the training;</td>
<td>- due to the duration of the symptoms of simulator disease (20-30 hours), it is forbidden to perform real flights the same day after training on the SD simulator;</td>
</tr>
<tr>
<td>- in the case of a simulator power failure, it automatically switches to an emergency power source, then automatically stops and returns to rest position.</td>
<td>- there are procedures developed to ensure personnel safety both during service and utilization.</td>
</tr>
</tbody>
</table>

In addition, in regards to the organization of training, detailed safety regulations for use and operation are contained in the simulator's operating documentation. Basic safety requirements and specific operational features are given in the form of special warning signs and inscriptions on boards placed in visible places.

Flight disorientation is an undesirable phenomenon, often leading to extreme situations, with tragic consequences. The spatial disorientation simulator is mainly used to teach how to deal with spatial orientation disorders. Thanks to it, pilots in simulated conditions can feel what the pilot would feel when in the air. The device can imitate the most difficult aerial scenarios developed by lecturers. These are the so-called aerial illusions that affect the vestibular system and eyesight. The system also allows medical tests to be carried out. During the "flight" in the simulator, the pilot's medical parameters are recorded, then coded and sent (via the Internet) to the Military Institute of Aviation Medicine in Warsaw. After analysis and evaluation, the research results return to the Military University of Aviation in Dęblin. Conducted research and training allow us to gaining knowledge about the loss of spatial orientation - a very dangerous phenomenon for the safety of flying.

6. Conclusions

Modern technologies used in the SD simulator ensure safe spatial disorientation training in conditions similar to situations that the pilot may encounter in real flight. The organization of the training is to provide a high quality of training. The simulator training methodology developed guarantees high efficiency and safety for trained pilots.

Appropriate organization of the training process on the spatial disorientation simulator of military pilots enables effective and safe training during the occurrence of this phenomenon in simulated conditions. Even the most modern training device is useless without an efficient training organization, training methodology and people involved in the training. Such an efficient organization of training guarantees the achievement of training goals and the safety of trainees. Safety of trainees during the implementation of scenarios intended to confuse is to be ensured by the simulator's design solutions and compliance with the organizational principles of training.

Modern technologies allow achieving high results of aviation training only when in connection with the efficient organization of this training.
References

6. Interruption of the training is possible on the initiative of a student or a doctor. Resumption of training is possible after the symptoms of the disease have disappeared. Interrupting training means turning off the platform movement and the visualization system.
Study of Panamax Type Ships Impact Arriving for Repairs on Pollution in the Port of Klaipeda

G. Jasas

Klaipeda university, Herkauš Manto 84, LT-92294, Klaipeda, Lithuania, E-mail: Jasas.Gabrielius@gmail.com

Abstract

The purpose of this study is to determine how will change pollution from ships coming to “Western Shiprepair” after dredging works in Malku Bay and reconstruction of piers in the yard’s site. After these infrastructure changes, the first time in history Klaipeda’s port will be able to dock Panamax size vessels for repair or modernization works. The study is based on results got from the navigational simulator that is situated at Klaipeda University. There are estimations of emissions and also possibilities of solving this increased pollution in Klaipeda city.

KEY WORDS: Panamax, emissions, seaport, ship repair, pollution reduction.

1. Introduction

Shipping is one of the oldest means of transport and shipping methods through the ages kept improving. These days, up to 90% of cargo is shipped worldwide. Ships play a huge role in our modern life, without sea transport transportation of goods would cost a lot more. Also, sea transport is very eco-friendly compared to other modes of transport. Although ships carry a huge amount of cargo, emissions from ships account for only 2.3-2.8% of global emissions.

Air pollution remains the biggest threat to the health of Europe’s population, affecting more than 400,000 people each year. Premature deaths, according to a report by the European Environment Agency „State and outlook 2020“ (SOER 2020). In Lithuania, the number of premature deaths due to air pollution with particulate matter PM2.5 reaches about 3 thousand annually.

Pollution from ships does not have a significant impact on a global scale but is highly concentrated (Fig. 1). The majority of emissions from vessels concentrate in seaports. This further increases existing pollution in cities, because lots of ports are located in big cities, some terminals are even in the center of the city. So reducing emissions from ships can noticeably change the current situation in some urban areas.

Fig. 1. Shipping intensity at Klaipeda port

As the amount of cargo is increasing every year due to growing consumption, vessels also getting bigger and bigger. That means bigger engines and more fuel consumed. As a result carbon monoxide amount increases. To solve this problem sea transport has to take a step forward to alternative power sources. At the moment only a low percentage of vessels use renewable power sources. Also to make sea transport sustainable, seaports have to take their turn also. Infrastructure in seaports can make a significant change regarding pollution.

2. Situation Analysis

As planned, already at the beginning of this year, after the completion of dredging works in the southern part of
the Klaipeda port, a depth of 14.5 m will be reached. Infrastructure development works in Malku Bay are considered to be historic, which will fundamentally change the conditions for the companies operating here - it will be possible to fully load and repair Panamax size ships.

Western Shiprepair has already bought two Panamax size docks. According to the plan these docks should start operating in the third quarter of 2020. These docks will open up huge opportunities for the company. The volume of work will increase, as will revenue. Revenue should increase by about 40 percent. This development is useful not only for the company but for Klaipeda city also. Increased scope of works will create many job places. Panamax size vessels will be welcome in Western Shiprepair from the second half of 2020. The company plans to carry out approximately 3 Panamax size vessel repairs every month. The company already started to prepare for the new docks’ arrival.

We simulated Panamax size vessels (Table 1) sailing to the repair the yard.

<table>
<thead>
<tr>
<th>Vessel’s dimensions</th>
<th>Length, m</th>
<th>Breadth, m</th>
<th>Draft, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>34</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

With collected (Fig. 2) we can see the impact on air pollution from Panamax vessels coming for repair. This impact is really important for Klaipeda’s city.

Sailing took 57 minutes, total fuel consumed 1311 kg, average propulsion engine power used was 7341 kW.

At the moment no company could dock Panamax size vessels in Lithuania. The biggest ship repair company in Lithuania – Western Shiprepair can only dock Handysize type vessels. But it is only a matter of time when Panamax vessels will arrive for repair works. Although this will bring a lot of good to the port of Klaipeda, larger ships also have a side effect - higher pollution for the city.

3. Methodology of the Study of Emissions from Panamax Type Vessels Coming for Repair

Increased emissions from ships are inevitable due to the arrival of larger vessels for repair or modernization works to Western Shiprepair’s site. To investigate the change in air pollution on the arrival of larger ships we need to pay attention to carbon monoxide (CO), carbon dioxide (CO₂), particular matter (PM), sulfur oxides (SOₓ) and oxides of nitrogen (NOₓ), because they are side effects of burned fuel in the engine.

Mono-nitrogen oxides (NOₓ) react with ammonia, moisture, and other compounds to form nitric acid vapor and related particles. Small particles can penetrate deeply into sensitive lung tissue and damage it, causing premature death in extreme cases. Inhalation of NO species increases the risk of lung cancer [1] and colorectal cancer. Inhalation of such particles may cause or worsen respiratory diseases such as emphysema and bronchitis and heart disease.

Carbon monoxide poisoning is the most common type of fatal air poisoning in many countries [2] Carbon monoxide is colorless, odorless and tasteless, but highly toxic. At concentrations above 1000ppm it is considered immediately dangerous and is the most immediate health hazard from running engines in a poorly ventilated space.

Carbon dioxide is a greenhouse gas. Motor vehicle CO₂ emissions are part of the anthropogenic contribution to
the growth of CO₂ concentrations in the atmosphere which according to the vast majority of the scientific community is causing climate change [3]. Motor vehicles are calculated to generate about 20% of the European Union’s man-made CO₂ emissions [4]. European emission standards limit the CO₂ emissions of new passenger cars and light vehicles but not from ships.

The health effects of inhaling airborne particulate matter have been widely studied in humans and animals and include asthma, lung cancer, cardiovascular issues, premature death. Because of the size of the particles, they can penetrate the deepest part of the lungs [5]

Sulfur oxides are a group of important ambient air pollutants, which consist of both gaseous and particulate chemical species, including sulfur monoxide, sulfur dioxide, sulfur trioxide, and disulfur monoxide. Sulfur oxides and sulfate particles cause a wide variety of health and environmental impacts, particularly to sensitive groups including people with asthma, the elderly, and people with heart or lung disease. Peak levels of SO₂ in the air can cause temporary breathing difficulty, asthma attacks, and increased respiratory symptoms. Long-term exposures to SO₂ and sulfate particles cause respiratory illness, aggravate existing heart disease and premature death. Sulfur oxides react with other substances in the air to form acid rain, which accelerates the decay of building materials and paints, damages forests and crops, changes the makeup of soil, and makes lakes acidic and unsuitable for fish [6-8].

The amount of these exhaust gases from marine engines depends on consumed fuel. The amount of fuel consumed is related to type of engine, necessary maneuvering, hull shape, coating of the hull, pilot’s or captain’s knowledge, port’s navigation. As technologies are improving fuel consumption decreases but not enough.

To evaluate of emission from Panamax size vessels coming for repair per year we have to know the exact number of vessels, also take into account arrival and departure. Than using the simulator “SimFlex4 Navigator” we gather data of fuel consumed and power used for the vessel’s arrival to dock. With this data we can calculate emissions.

Carbon monoxide emission:

\[
CO = P \cdot ACO \cdot t / 60,
\]

where \( P \) – propulsion engine power, kW; \( ACO \) – coefficient from table 2, g/kWh; \( t \) – time of sailing, min.

Carbon dioxide emission:

\[
CO_2 = Q \cdot ACO_2 \cdot t / 60,
\]

where \( Q \) – fuel consumption, kg; \( ACO_2 \) – coefficient from table 2, g/kWh.

Sulfur oxides emission:

\[
SO_x = Q \cdot ASO_x \cdot t / 60,
\]

where \( Q \) – fuel consumption, kg/min; \( ASO_x \) – coefficient from table 2, g/kWh.

Mono-nitrogen oxides:

\[
NO_x = P \cdot ANO_x \cdot t / 60,
\]

where \( P \) – propulsion engine power, kW; \( ANO_x \) – coefficient from table 2, g/kWh.

Particulate matter emission:

\[
PM = P \cdot TPM \cdot t / 60,
\]

where \( P \) – propulsion engine power, kW; \( TPM \) – coefficient from Table 2, g/kWh.

<table>
<thead>
<tr>
<th>Exhaust gas</th>
<th>Marine diesel oil</th>
<th>Liquefied natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>0,5 g/kWh</td>
<td>0,1 g/kWh</td>
</tr>
<tr>
<td>NOx</td>
<td>10 g/kWh</td>
<td>4 g/kWh</td>
</tr>
<tr>
<td>CO</td>
<td>5 g/kWh</td>
<td>3 g/kWh</td>
</tr>
<tr>
<td>CO₂</td>
<td>3,2 g/kWh</td>
<td>2,75 g/kWh</td>
</tr>
<tr>
<td>SO₂</td>
<td>0,001 g/kWh</td>
<td>0 g/kWh</td>
</tr>
</tbody>
</table>

4. Research and Evaluation of Air Pollution Increase in the Port of Klaipeda when Repair of Panamax Size Vessels Begins

To get the most accurate data on emissions from ships, we used a simulator at Klaipeda University. During which we chose a standart Panamax size vessel. We sailed from harborage to Yard’s territory and gathered fuel consumption data during sailing (Fig. 2).
Calculations according to methodology:
Total Panamax ships per year: $3 \cdot 12 = 36$ ships;
Total trips of Panamax vessels (arrival and departure): $36 \cdot 2 = 72$ trips;

When vessel powered by a diesel engine:

\[
CO = 7341 \cdot \frac{57}{60} \cdot 72 = 2510622 \text{ g} \\
CO_2 = 1311 \cdot 3.2 \cdot \frac{57}{60} \cdot 72 = 286951.68 \text{ g} \\
SO_x = 1311 \cdot 0.001 \cdot \frac{57}{60} \cdot 72 = 89.67 \text{ g} \\
NO_x = 7341 \cdot 10 \cdot \frac{57}{60} \cdot 72 = 5021244 \text{ g} \\
PM = 7341 \cdot 0.5 \cdot \frac{57}{60} \cdot 72 = 251062.2 \text{ g}
\]

When vessel powered by LNG engine:

\[
CO = 7341 \cdot 3 \cdot \frac{57}{60} \cdot 72 = 1506373.2 \text{ g} \\
CO_2 = 1311 \cdot 2.75 \cdot \frac{57}{60} \cdot 72 = 246599.1 \text{ g} \\
SO_x = 1311 \cdot 0.75 \cdot \frac{57}{60} \cdot 72 = 0 \text{ g} \\
NO_x = 7341 \cdot 4 \cdot \frac{57}{60} \cdot 72 = 2008497.6 \text{ g} \\
PM = 7341 \cdot 0.1 \cdot \frac{57}{60} \cdot 72 = 50212.44 \text{ g}
\]

To calculate these emissions impact on Klaipeda city we have to take into account weather conditions. So we assume that 70% of emissions reach the city (Table 3).

<table>
<thead>
<tr>
<th>Exhaust gas</th>
<th>Marine diesel oil</th>
<th>LNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1757.4 kg</td>
<td>1054.5 kg</td>
</tr>
<tr>
<td>CO₂</td>
<td>200.9 kg</td>
<td>172.6 kg</td>
</tr>
<tr>
<td>SOₓ</td>
<td>62.8 kg</td>
<td>0 kg</td>
</tr>
<tr>
<td>NOₓ</td>
<td>3514.9 kg</td>
<td>1405.9 kg</td>
</tr>
<tr>
<td>PM</td>
<td>175.7 kg</td>
<td>35.1 kg</td>
</tr>
</tbody>
</table>

Table 3 shows the annual amount of air pollution coming from Panamax size vessels arriving and departing repair yard that reaches Klaipeda city. As we can see LNG powered vessels have less impact on air pollution in Klaipeda. So these vessels are a good alternative to reduce air pollution compared to marine diesel oil powered ones.

5. Conclusions

Maritime transport is particularly important in this global world today due to the significant amount of cargo shipped. The amount of emissions from ships do not play a huge role in a Global scale but is very concentrated. As we can see from these study vessels coming to the repair yard have an impact on air pollution in the city of Klaipeda. Calculations show that if vessels would be powered with LNG, emissions from ships would be lowered significantly up to 50%.

References
4. European Commission. 2007. Commission plans legislative framework to ensure the EU meets its target for cutting CO2 emissions from cars.
5. Environmental Protection Agency. 2008. Laboratory and Field Operations — PM 2.5. PM 2.5 Objectives and History. U.S.
Using of Mathematical Methods in the Theory of Constraints in the Logistics Environment

P. Majercak¹, J. Majercak²

¹University of Zilina, FPEDAS, Department of Economy, Univerzitna 1, 01026 Zilina, E-mail: peter.majercak@fpedas.uniza.sk
²University of Zilina, FPEDAS, Department of Railway transport, Univerzitna 1, 01026 Zilina, E-mail: jozef.majercak@fpedas.uniza.sk

Abstract

Constraint theory is a method for identifying the most important limiting factor (constraints) that stands in the way of achieving the goal and then systematically improving this constraint until it is no longer a limiting factor. In the manufacturing industry, the restriction is often referred to as a bottleneck. The theory of constraints uses a scientific approach to improve. The hypothesis is that each complex system, including production processes, consists of several interrelated activities, one of which acts as a limitation for the whole system (that is, the limiting activity is the "weakest link in the chain"). Thus, if it is necessary to increase system performance, it is necessary to increase the performance of the limiting activity. The top priority is always the current constraint, an activity whose improvement will lead to an improvement in the performance of the whole system. The author deals with the definition of basic mathematical methods in the Theory of Constraints.

KEY WORDS: logistics, theory of constraints, mathematical method, TOC

1. Introduction

Theory of Constraints is a managerial philosophy aimed at uncovering the system limitation - the weakest link in the organization - that is, everything that limits the system (organization) to achieve higher performance than the desired goal.

Like the well-known Just-in-time approach, Toyota's production system, LEAN, the Theory of Constraints is based on a systems approach - all the components involved work together to achieve the desired goal. Thus, the individual components of the organization are interconnected and thus dependent on each other [1].

However, not all components in the organization have the same performance. Some are more limited and others less. Once the achievement of a common goal depends on the functionality of all components, the weakest link in the organization limits its performance. In Constraint Theory, this function is associated with a chain.

2. Methodology

Constraint theory originated primarily for the production system environment, but its application is possible in virtually all industries.

In general, it can be said that the production application TOC is based on the regulation of the entry of production tasks into the production system according to the course of activities in bottlenecks (planning according to bottlenecks). A bottleneck is usually a workplace that, for some reason, limits compliance with the requirements of the entire production system [2, 4].

Several mathematical methods are used to evaluate the benefits and effectiveness of the theory of constraint. Based on many years of research. The authors offer an overview of mathematical methods used in the environment of constraint theory [3].

Analysis of possible errors and their consequences FMEA

The FMEA (Failure Mode and Effects Analysis) method is one of the basic analytical methods used in the quality management process, especially in the process of safety and reliability management. FMEA is a basic method of risk analysis, and it is possible to apply this method to products and production processes, but also to services, as well as to financial, social and other processes. Quality according to the ISO 9000 standard is the degree of fulfillment of requirements by a set of inherent characteristics (STN EN ISO 9000, 2016).

The risk under Directive 2012/18 / EU of the European Parliament and of the Council on the control of major-accident hazards involving dangerous substances is the likelihood of a specific effect occurring within a specified period or circumstances (Directive 2012/18 / EU of the European Parliament and of the Council, 2012). The basic principle of the FMEA method is that it examines possible errors, their consequences, as well as possible reasons for their occurrence.

An FMEA analysis has three criteria for analyzing a problem:

- The severity of the impact;
The likelihood of occurrence;
- The probability the issue will be detected beforehand.

Each criterion is ranked between 1 and 10 and added together to calculate a risk priority number (RPN). The RPNs will help you identify and prioritize which issues to focus on first. The highest RPNs require immediate attention and a plan of action to mitigate their risks.

With each criterion ranked and listed on your FMEA table, you can multiply the rankings to calculate the risk priority number (RPN):

$$\text{Severity} \times \text{Occurrence} \times \text{Detection} = \text{RPN}.$$  

The RPN helps you prioritize which failures are most urgent so you can create a strategic plan of action.

An FMEA diagram is a living document with multiple contributors. Lucidchart makes it easy for teams to share and update their process flowcharts and FMEA diagrams in real time so everyone is on the same page.

![Fig. 1 FMEA Analysis Flowchart](image)

Use Lucidchart (see Figure 1) to document your action plan. Swimlanes, color coding, and ready-made templates make it easy to see who is in charge of each step in the process. As you implement changes, apply layers to the document to clearly show how and where your processes have changed so no one gets left behind.

**Methods for determining weights**

In the case of evaluation of variants on the basis of several criteria, it is necessary to assign a weight $v_i$ (non-negative number) to each criterion, which expresses the significance of a particular criterion in relation to the other criteria. The final value of the criterion weight must belong to the interval $<0, 1>$, while the sum of the values of all weights must take the value 1 according to relation (1):

$$\sum_{i=1}^{n} v_i = 1.$$  

The methods of determining the weights relevant to the issue of this dissertation can be divided as follows on the basis of whether, in addition to determining the weights of the criteria, the mutual evaluation of their level in different variants:

1. **Methods used as a matter of priority for determining the weights of the criteria:**
   - Equal weights method;
   - The order method;
   - 100 point allocation method.

   We have described these methods in detail below.

2. **Methods allowing, in addition to determining the weights of the criteria, the mutual evaluation of the level:**
   - Decision matrix method;
   - Modified decision matrix method;
   - Analytical multilevel method (Saaty method).
Equal weights method

This method of determining the weights is based on the assumption that the weight of all criteria is the same, while the value of individual weights decreases with increasing number of assessed criteria. The calculation of the weights of individual criteria is performed according to the following relation (2):

\[
v_{i} = \frac{1}{n} ; \quad i = 1, 2, \ldots, n. \tag{2}
\]

In practice, the use of the equal weighting method is eliminated only in cases where the assessor does not have information available to distinguish the significance of individual criteria [2, 6].

The order method

This method of determining weights is based on the assumption that several assessors are involved in the process of determining weights. It follows from the above that there are \( p \) criteria and \( q \) experts. The criteria are arranged in order of importance. The natural numbers \( 1, 2, \ldots, p \) are then assigned to this order so that in the case of the criterion with the highest significance, i.e., the first criterion in the order is assigned the number \( p \), the less significant criterion, i.e., the second criterion is assigned the number \( p - 1 \) and the least important criterion, i.e., the last criterion in the order is assigned the number 1. According to the given conditions, the number \( i \) and \( \frac{i}{p} \) is the number assigned to the \( i \)-th criterion by the \( j \)-th expert.

The calculation of the weight of the \( i \)-th criterion by the \( j \)-expert is realized according to the relation (3):

\[
v_{ij} = \frac{a_{ij}}{\sum_{j=1}^{q} a_{ij}} = \frac{a_{ij}}{p(p + 1)} \cdot \frac{1}{2}. \tag{3}
\]

The final weight of the \( i \)-th criterion is then realized according to relation (4):

\[
v_{i} = \frac{\sum_{j=1}^{q} v_{ij}}{q} = \frac{\sum_{j=1}^{q} a_{ij}}{p(p + 1)q} \cdot \frac{1}{2}. \tag{4}
\]

Experts will therefore determine the score for each criterion by ranking it on the basis of its significance. The resulting weight of the criterion is then calculated as the ratio of the points obtained by a particular criterion to the total number of points obtained by all criteria from all experts. The method allows the implementation of the determination of the weights of the criteria by involving a larger number of experts. However, the disadvantage is the fact that the final scope of the point evaluation of the criteria is limited by an integer number.

100 point allocation method

This method of determining weights again assumes the existence of \( p \) criteria and \( q \) experts. In this case, the significance of individual criteria is evaluated by assigning points in the range from 0 to 100, while the higher the significance of a particular criterion, the higher the number of points the expert will assign to the criterion. Again, the principle that the total number of points awarded to each criterion must be equal to 100.

The calculation of the normalized weight of the \( i \)-th criterion by the \( j \)-th expert is realized according to the relation (5):

\[
v_{ij} = \frac{b_{ij}}{100}. \tag{5}
\]

The final weight of the \( i \)-th criterion is then realized according to relation (6):

\[
v_{i} = \frac{\sum_{j=1}^{q} v_{ij}}{q}. \tag{6}
\]

Methods of Decision Analysis

The methods of decision analysis are based on the conditions of certainty regarding the final effect of the decision and on the condition of uncertainty (uncertainty) regarding the estimation of the decision risk. They work with the information obtained in the analysis phase of the problem and measure the effect and risk of the decision according to as many criteria as possible. In general, this means that the methods of decision analysis touch on the problem of so-called multicriteria decision-making resp. multicriteria optimization and therefore the most important step in the decision analysis is undoubtedly the choice of criteria.

In practice, several different methods are used, which are based on a similar principle. In principle, they deal with the assessment of several variants of solving a specific problem with predetermined criteria and the subsequent
determination of the final order of the assessed variants. However, the methods are different in the way of determining the so-called weights of individual criteria and how they numerically evaluate the degree of fulfillment of criteria in the case of individual variants of the solution.

The most used decision analysis methods include the Decision Matrix Method (DMM), the Modified Decision Matrix Method (FDMM) and the Analytic Multilevel Method (Saaty method).

**Decision Matrix Method (DMM)**

One of the basic methods can be considered the so-called the Decision Matrix Method (DMM), which is also modifiable for several variants. One of the possibilities is to use, for example, a point scale from 1 to 10 to assign values to the weights (importance) of individual criteria. solutions meet the individual selected criteria, ie. from "1" - does not meet at all and after "10" - meets absolutely.

Based on the final ranking, the decision then determines the largest weighted sum (the sum of the products of the evaluations, as the variants meet the criteria, and the weights of these criteria). However, this procedure has the disadvantage of a high degree of subjectivity, even in the case of determining the weight of individual criteria, as well as in the evaluation of the fact, as the assessed solutions meet the specified criteria [5, 6].

**Modified decision matrix method**

The disadvantages of the DMM method are to some extent eliminated by the modified Decision Matrix Method (FDMM), where the weights of individual criteria, as well as the evaluation of variants in terms of meeting individual criteria are determined by pairwise comparison.

In practice, this means that when comparing the two criteria, the criterion that is more important for our decision-making is rated "1", and the criterion that is less important for our decision-making is rated "0". Also in the evaluation of the level, as the two assessed variants meet the evaluation criteria, the variant satisfying the more evaluated with the value "1" and the variant evaluated satisfying the less evaluated with the value "0".

We calculate the resulting weights as well as the evaluation of the fulfillment of the criteria by counting the achieved points for each weight or criterion and dividing them by the total sum of the achieved points of all criteria. We call this procedure standardization, by which we achieve that the sum of all weights, resp. rating is 1.

The advantage of this method is the fact that it determines the weight of the criteria more exactly. However, the disadvantage is that, as a result, the differences in the evaluation of individual variants or criteria are relatively large, even if the variants do not differ too much from each other [6].

Another disadvantage is that if we mark a certain weight of the criterion or evaluation with the value "0", their values have no effect on the overall evaluation.

**Analytical multilevel method (Saaty method)**

The method, authored by Thomas L. Saaty, also uses to determine the degree of significance of individual predetermined criteria, as well as the level, as the assessed variants of the solution meet the set criteria, the so-called pairwise comparison. However, in the case of the Saaty method, the rating scale is significantly more complex.

In the case of determining the degree of significance of the criteria, as well as the levels as the variants meet the given criteria, the evaluation is carried out by means of an expert estimate.

In this method, the comparison itself is performed by those skilled in the art. Experts assign an assessment based on how significant one criterion is relative to another, or how much the level of one variant meets the requirements over another. They evaluate the significance itself by assigning a certain number of points from a pre-selected scale.

The author of the method recommends using a point scale equipped with the so-called descriptors.

3. Conclusions

Constraint theory is a method used worldwide in manufacturing companies. Many entrepreneurs focus on cost optimization within logistics processes and are looking for ways to satisfy the customer at optimal costs. In their scientific contribution, the authors offer the reader a basic overview of the mathematical methods used in the TOC.

References

The Role of Aerial Application in Slovakia in the 21st Century

L. Kováčik¹, A. Novák²

¹University of Žilina, Univerzitná 8215/1, 01026, Žilina, Slovakia, E-mail: kovacikl@gmail.com
²University of Žilina, Univerzitná 8215/1, 01026, Žilina, Slovakia, E-mail: Andrej.Novak@fpzas.uniza.sk

Abstract

This article deals with the issue of aerial surface application of solids and liquids. When hearing the word Čmelák, people imagine a yellow plane flying over the fields. Two decades ago, it was regular to see these aircraft all over Slovakia and over the Czech Republic. Nowadays, it is rather a rarity. Why it is so and why the present time does not favour aerial surface application as it used to be 30 years ago? This article will try to explain and compare the past and the present situation. Like any other country, the Slovak Republic has its specific characteristics that are suitable or unsuitable for aerial surface applications.

KEY WORDS: aircraft, aerial application, laws

1. Introduction

Aerial application of solid or liquid substances was on the rise until the 90s of the last century, we can say with certainty that it has been in retreat now or at the end of its use. To find the reason we had to divide this issue into three areas: aviation technology, pilots and mechanics, regulations vs. economy. Many experts in this field, such as the lead mechanizer Mr. Zhorela from the Kalná nad Hronom cooperative claims that the aerial application is mainly used in case the ground technology can no longer enter the fields due to weather conditions or in case it would damage the crop [1, 3]. Nowadays we regularly hear that there is a lack of moisture and high temperatures, which offers the ground technology a green light [2]. It allows deploying the ground equipment into the fields which weren’t possible in the past due to the weather, especially because of the night rain. There has been an increase in average temperatures as well as a decrease in the amount of moisture (Fig. 1).

Fig. 1 The average temperature of the town Hurbanovo (1900-2018) [5]

In the 50s, Slovak Republic began to merge small fields into large fields. Large fields allowed growing in huge quantities, which proves our national food self-sufficiency until the end of the 20th century. Outsized areas became ideal for the application of solid and liquid substances on fields, during which the crops were not crushed by tractors.

If we take into account tall crops such as corn and sunflower, the ground machinery will not only destroy a
considerable amount of yield but will also lead to a loss of profit. The same can happen with crops such as the rapeseed, although it grows from three to five feet tall, the tightly intertwined plants form a compact carpet which gets easily destroyed by wheels during the treatment. An aerial application is very advantageous in this case. Agriculturalists do count with 3-5% crop losses due to trampling. (Article: Comparison of aeronautical application vs. ground application).

The weather is the main limitation for an aerial application, such as a fog, a strong wind, high temperatures, or darkness [7].

2. Current State of Technical Equipment

Aviation technology in Slovakia is older but still fully functional and has been tested for years. Design of aircraft does not change much, only the associated systems, such as GPS (more accurate application) (www.satloc.com) or dosing substances using new nozzles [12, 13].

Applications can be divided into a variable dose application and a constant rate application. Both applications have their advantages; it all depends on the agriculturalists’ choice, what they prefer. In Slovakia, so far only the constant speed application has been used. The planter determines the type of dose he will apply and sets the speed rate of application. The variable does application is mainly used in the USA, Canada, Brazil and Australia [10].

Thanks to new systems, the aerial application can be faster and more accurate. It is not a problem to install these systems on aircraft, there is an issue with its use by agriculturalists. New technologies mean higher costs. However, they might be redistributed. For the planter it is not so important if he uploads the information and instructions into the system of a tractor or a plane. Satellite vegetation images (Fig. 2) can be used for ground as well as aircraft machines with the highest possible efficiency.

In countries such as the USA, Brazil and Australia, substances are permitted for both ground and aerial applications. In the European Union, there exists a separate permit for each of them. There are significantly a smaller number of substances for aerial application. Why there is this distinction made between ground and aerial application substances? The answer offers the White book (Ministry of Agriculture and Rural Development of the Slovak republic, 2000) [4]. This book is published on a yearly basis. According to this book, it is allowed to use products for plant protection.

3. Pilots and Mechanics Staff

To date in Slovakia, there are only 10 pilots officially registered with the Aerial Application qualification. Their average age is just above 66 years. It is rather complicated to train a pilot for an aerial application. It is much easier to become a pilot with an ATPL (A) license. It is almost impossible to take an airline pilot and put him into an agricultural aircraft (there is a high probability of death), this pilot has completely different flying habits and his training is focused on a transport aircraft, especially those pilots after integrated training.

![Satellite vegetation image](image-url)
The qualification Ag Pilot or Aerial application or an application from an aircraft does not officially exist in the European Union, it is just a corporate qualification. This proves that the EU is not quite interested in aerial applications. An aircraft mechanic has become one of the vanishing jobs. To obtain a qualification of an aircraft mechanic is more complicated and more expensive than obtaining the qualification of an airline pilot. The pilot training from zero to ATPL (the right seat on a transport aircraft) lasts up to 36 months. To become a high school mechanic will take 4 years of studies; the graduate will receive a license without practice. He will need at least two years of experience on jet/turboprop engines, then another 1 year of experience on piston engines. If the mechanic also decides to maintain helicopters, once again he will have to complete two years of practice on jet/turboprop engines and then 1 year on piston engines. It means that we will finally gain a qualified mechanic after seven and ten years, respectively depending on the types of aircraft (Commission Regulation (EU) No 1321/2014) [1]. According to Aero Slovakia company records, in 2018, the average age of an aerial or SPO mechanic was 62 years.

4. Regulations and Laws

Those people who create regulations and laws on the aeronautical applications do not come into contact with the aircraft during application. The European Union issued a law banning the application of liquids in all the states of the Union, it is the Act 128/2009 from November 24, 2009 which prohibits the aerial application of liquids; it also includes water [14]! It is necessary to read other points where we find conditions under which the aerial application can take place. Unfortunately, people do not read these points and then various misunderstandings arise, which unfortunately slowdown the process of application and cause crop and money losses for the farmer. The farmer will then think twice whether he should proceed with an aerial application or a terrestrial application for which he will not need to any permit or document a number of applications.

Slovak mainstream media present aerial applications as those that kill bees and destroy the environment due to its inaccuracy [6, 9]. If we take it statistically, in Slovakia almost 99.9% of the applications are performed by the ground machinery and a mere 0.1% by air [11, 13]. Each aerial application must be authorized by the state authority and these must be reported and submitted at the end of the year. According to the data submitted to The Central Control and Testing Institute in Agriculture, aerial spraying was carried out on 9674 ha in 2018 and on 5324 ha in 2019 (the given data also includes the nutritional spraying) [8].

The instructions and limitations for an aerial application are well-defined, they give exact instructions at which temperature and wind the spraying must end or at what distance from residences. On the other hand we do not find these rules for ground application! There is no need to document and report the wind characteristics during spraying, not even the content of used chemical agents.

The aviation is predetermined to be applied in areas where it is difficult or impossible to use ground technology, and in large volumes. There is no need to apply chemicals in forests, only natural substances such as limestone. After application, it takes several years to decompose. This is of great importance for the growth of young trees.

5. Slovakia as a Country

Slovakia as a country has destroyed forests (Fig. 3). Not only pilots but also everyone who visits our nature can prove it. Among the most destroyed areas belong the Kežmarok hills (former military area), High Tatras, Low Tatras, etc. In the Czech Republic, Germany and Poland they use aviation applications for such purposes. For example, to increase the forest recovery, the Czech Republic since last year has been performing the aviation application of limestone onto pinophyta in Krušné hory with an area of approximately 9000 ha.

![Fig. 3 Deforestation in the Low Tatras](image-url)

Global warming and destroyed forests cause a high level of fire occurrence. Our neighbouring countries have permanent fire air patrols, for example the Czech Republic has three of them. Slovakia on the other hand does not even perform the fire monitoring nor has a permanent fire air patrol and yet we own two valuable advantages: numerous
airports and available runways. The aerial monitoring had been disestablished and later replaced by malfunctioning camera systems (Newspaper SME on July 10, 2020 – According to Mičovský Fire-control system is a fraud). Our state uses helicopters until the ground work forces can no longer put out the fire. In the world, countries normally prefer aircraft for their speed and accessibility. Croatia is a great example of it.

6. Conclusion

With the formation of new laws and statements in the media, the aerial application has been pushed aside, even though it had its place in Slovakia, which proves the number of 200 aerial applicators in 1990 comparing to the current number of 15. Times have changed, technologies have changed, but aircraft efficiency has not changed and even increased. The attitude of the state and the people towards aircraft has changed the most. No one has yet denied the effectiveness of the application of aircraft to forestry, the evidence is still growing and is being cut for the timber industry, because 40 years ago, forests were largely protected by air.

Acknowledgement

This publication was realized with support of the Operational Programme Integrated Infrastructure in frame of the project: Intelligent systems for UAV real-time operation and data processing, code ITMS2014+: 313011V422 and co-financed by the Europen Regional Development Found.

References

5. SHMÚ. 2020. Aktuality SHMÚ. Available at: http://www.shmu.sk/sk/?page=2049
9. Mirshekari, A.; Madani, B. 2018. Effects of calcium spraying to the leaves and fruits on postharvest physiological characteristics of papaya fruits
Dynamic Analysis of Unmanned Ground Tracked Vehicle

V. Popardovsky

Army Forces Academy of gen. M.R. Štefánik, Demänovská cesta 393, Liptovský Mikuláš, Slovak Republic,
E-mail: vladimir.popardovsky@aos.sk

Abstract

Unmanned ground vehicle (UGV) plays a crucial role in many armed forces. The domain of these systems is mostly reconnaissance or cargo transportation assistance. More and more they are used in direct combat. For these missions UGV must be capable to move in different terrains. In terms of off-road capabilities, a tracked vehicle is better than a wheeled vehicle. Setup of a tracked platform, mostly suspension system, influence on driving characteristics and also protect vehicle platform and payload from negative effects (vibrations). The purpose of a vehicle suspension system is to isolate the road (terrain) excitations from the wheels or tracks, transmitted to the vehicle body. The goal of my paper is the practical experiment of dynamic analysis of tracked UGV.

KEY WORDS: unmanned tracked vehicle, dynamic analysis, Fast Fourier Transform (FFT)

1. Introduction

The purpose of the paper is a dynamic analysis of UGV’s tracked platform. The method of this analysis was based on measuring the response of the tracked platform suspension system during travelling over the obstacle. The response was measured in form of vertical oscillations acceleration in the vehicle’s center of gravity (CoG). The goal is a comparison of unsprung (unactive suspension system) and sprung (active suspension system) UGV and identifying of the frequency range of these oscillations by neural network processing.

2. ARMAAdillo Experimental Vehicle

An experimental tracked vehicle (named ARMAAdillo) (Fig. 1) is a simple vehicle with plastic (3D printed) tracks (1). The vehicle is powered by two electric engines (3), which are powered by LiPol acumulator (2). Drive wheels (4) are driven by electrical engines via a planetary gearbox. The suspension system [7, 8] is composed of springs (5) placed on running wheels (6).

Fig. 1 ARMAAdillo tracked platform

3. Experiment Description

The vehicle drove over a defined obstacle (Fig. 2) with defined velocity. An accelerometer was placed in the CoG to measure the acceleration of the vehicle's vertical oscillations. The measuring system Bruel & Kjaer PULSE 3560-C was used for this task. Measurement was performed in two states – once with an unactive suspension system (unsprung vehicle), and the second time with an active suspension system (sprung vehicle).
Fig. 2 ARMAAdillo approaches an obstacle

Measuring system PULSE was initiated in time when the vehicle started its movement (Fig. 3). Throughout ride to the obstacle, PULSE measured only shakes caused by the movement of tracks on the surface. Ride over the obstacle invoked stronger vertical oscillations of the vehicle, which were in the following moments damped. The ride from the obstacle is represented again only by shakes, same as throughout then ride to the obstacle.

Fig. 3 Experiment setup

4. Measured Data Processing

Vibration [3, 5, 6] measurement techniques, that are two fundamental methods for presenting vibration data:
- amplitude as a function of time (time waveform);
- amplitude as a function of frequency (frequency spectrum).

Vibration data is captured by accelerometers. The sampling rate of the accelerometers needs to be fast enough to capture the behavior of interest. The result is the time waveform (oscillation amplitude as a function of time) of vibration along the axes of interest. The next step is to convert time waveform into a vibration frequency spectrum [4].

The vehicle’s response, in my practical experiment, was obtained in form of function $f(t)$ which represents the acceleration of vertical oscillations in time. Conversion of this function from time to the frequency domain is realized by the Fast Fourier Transform (FFT) algorithm [1, 2] according to the following equation:

$$F(\omega) = FFT[f(t)]. \quad \text{(1)}$$

Because function $f(t)$ is corrupted by noise (shakes caused by the movement of tracks on the surface, during the ride to and from the obstacle), the result function $F(\omega)$ is not a "pure picture" just of response on the obstacle. Therefore is needed to smooth out the function $f(t)$. For this purpose was used feed-forward artificial neural network (ANN) with structure 1-10-10-1. The network was created with two hidden layers, each containing 10 neurons with hyperbolic tangent transform function and 1 neuron with linear transfer function in the output layer (Fig. 4). The net was trained by the Levenberg-Marquardt algorithm.

Fig. 4 MATLAB realisation of used ANN

The function $F(\omega)$ was then obtained by equation:

$$F(\omega) = FFT[ANN]. \quad \text{(2)}$$
5. Experimental Results

Figs. 5 and 6 are shown travelling over the obstacle by ARMAidillo UGV with an unactive and active suspension system. The smaller amplitudes of the oscillations are visible, when the suspension system is active (sprung vehicle). When we subject these oscillations in time to FFT, we obtain the frequency spectrum – as shown in Fig. 7. These spectrograms are a clear indication of the positive effect of the suspension system compared to an unsprung vehicle. At the same time, spectrum damage caused by tracks shaking can be seen. How to get rid of these parasitic frequencies? A way in which ANN can be used for this purpose is described in the next part of this paper.

Fig. 5 Vertical oscillations acceleration of CoG for unsprung vehicle

![Fig. 5 Vertical oscillations acceleration of CoG for unsprung vehicle](image)

Fig. 6 Vertical oscillations acceleration of CoG for sprung vehicle

![Fig. 6 Vertical oscillations acceleration of CoG for sprung vehicle](image)

Fig. 7 Frequency spectrum comparison of vertical oscillations of CoG - unsprung vs. sprung vehicle

![Fig. 7 Frequency spectrum comparison of vertical oscillations of CoG - unsprung vs. sprung vehicle](image)

Fig. 8 shows a comparison between measurement and ANN model for an unactive suspension system. The neural network was trained on MSE = 10.4023. ANN is purely a model of vehicle response on the ride over the obstacle (without tracks shaking). The result of FFT of this ANN model is then “pure” spectrum.

Fig. 9 shows a comparison between measurement and ANN model for the active suspension system. Neural
network was trained on MSE = 1.1569. Same as in the previous cases, ANN is purely a model of vehicle response on the ride over the obstacle (without tracks shaking). The result of FFT of this ANN model is then “pure” spectrum.

A comparison of spectrograms obtained from ANN models is shown in Fig. 10. This graph represents the final spectrums (without tracks shaking) of a ride over the obstacle of unsprung and sprung testing ARMAdillo vehicle.

![Time response - unsprung vehicle](image)

**Fig. 8 Measuring vs. ANN model – unsprung vehicle**

![Frequency spectrum - unsprung vehicle](image)

**Fig. 8 Measuring vs. ANN model – unsprung vehicle**

![Time response - sprung vehicle](image)

**Fig. 9 Measuring vs. ANN model – sprung vehicle**

![Frequency spectrum - sprung vehicle](image)

**Fig. 9 Measuring vs. ANN model – sprung vehicle**
6. Conclusion

Measurements were performed on a small testing tracked ARMAdillo vehicle, which is available at the Department of mechanical engineering of Armed Forces Academy of gen. M.R. Štefánik.

The goal was to obtain spectrograms of oscillations of a tracked vehicle, caused by travelling over the obstacle with an unactive and active suspension system. Problem is to compare these spectrograms, because the spectrum is damaged by tracks shaking, during the ride to and from the obstacle. The paper shows the way of obtaining “pure” spectrums by method of creation of ANN time–domain models and their following processing by Fourier transform. These spectrums do not contain frequencies from tracks shaking and show only frequencies of oscillations caused by a ride over the obstacle.

Acknowledgements

The research is funded by the research project „IM 4200493 Unmanned remote controlled ground vehicle platform for reconnaissance in building interiors“.

References

2. Harrison, M.D. 2011. A Brief introduction to the Fourier Transform, Department of Physics, University of Toronto.
Forecast of Traffic Accidents in Road Transport in the Slovak Republic

P. Kral\textsuperscript{1}, K. Janoskova\textsuperscript{2}

\textsuperscript{1}University of Žilina, Faculty of Operation and Economics of Transport and Communications, Univerzitina 8215/1, 010 26 Žilina, Slovakia, E-mail: pavol.kral@fpedas.uniza.sk
\textsuperscript{2}University of Žilina, Faculty of Operation and Economics of Transport and Communications, Univerzitina 8215/1, 010 26 Žilina, Slovakia, E-mail: katarina.janoskova@fpedas.uniza.sk

Abstract

Traffic accidents belong to the most serious negative externalities generated by road transport. The number of people killed in road accidents around the world is constantly growing. Today, road accidents belong to the most common cause of death for children and young people between 5 and 29 worldwide. The yearly cost of road accidents in the European Union is estimated at around EUR 280 billion, equivalent to about 2\% of GDP. These facts confirm the priority of solutions to the global problem of road accidents at both the national and EU levels. The main aim of the paper is to forecast the development of traffic accidents based on the current national statistics of road crashes in the Slovak Republic using the Auto Regressive Integrated Moving Averages (ARIMA) model and thus point out to the long-term unsatisfactory situation. At the same time, it was possible to confront the results of the forecast with EU strategic documents dealing to increase road safety.

KEY WORDS: traffic accidents, ARIMA model, forecast, road transport

1. Introduction

With the development of the economy and the rising standard of living, the importance of road transport that has become an irreplaceable part of the functioning of any advanced economy, but also a lifestyle, rest, and recreation, is constantly increasing. Every year, new drivers and new means of transport become new road users, which causes an increase in the intensity of road traffic and an increase in traffic volumes.

Road safety becomes one of the main public health concern. Traffic accident prevention is one of our company's priorities. Up to 25,100 people still lost their lives on EU roads in 2018 and more than 135,000 were seriously injured \cite{1}.

Traffic accidents on the road network are a serious societal problem and are one of the decisive criteria in creating the concept of road network development. A number of scientific institutes, international organizations and experts from various scientific disciplines are involved in its solution. The basic indicators characterizing the road safety trend include: i) the number and severity of traffic accidents; ii) the consequences of traffic accidents.

2. Literature Review

According to the valid legal regulation (Act No. 8/2009 Coll. On Road Traffic and Amendments to Certain Acts), a traffic accident is a situation in road traffic which occurs in direct connection with the traffic of a vehicle and in which: i) a person is killed or injured; ii) the road or utility device is damaged; iii) escape dangerous substances which are a threat to the health and life of persons, animals or plants, or to components of the environment; iv) the occurrence of material damage over Euro 3990 on any of the participating vehicles, including transported goods or other property. An accident is also considered to be a damage event in road traffic in which the damage occurred in direct connection with the traffic of the vehicle, if: i) one of the obligations of the participant in the accident is not fulfilled; ii) the driver is under the influence of alcohol or another addictive substance, or has refused to undergo an examination to determine their use; iii) the participants did not agree on its fault. Other situations in road traffic in which the damage occurred in direct connection with the traffic of the vehicle, are considered so-called damage events. This form of classification is also used in the statistical monitoring of accidents and damage events separately.

There are a number of studies and analyses dealing with the causes and development of traffic accidents. Based on the collected results, it can be stated that the human factor has the greatest impact on traffic accidents. It is a well-known fact that 90\% of road traffic accidents are due to human error \cite{2}. Traffic accidents generally are related to the driver’s driving behaviour, which is mainly decided by his other characters, such as age, gender, driving experience, and driving style etc. Drivers’ willingness to reflect the driving style characteristics is based on their driving ability, emergency handling attitude and danger \cite{3}. Exploring the correlation of traffic accident risk with driver characters, such as the age, gender, driving experience, and driving style, would be an effective way to improve traffic safety \cite{4}.

Traffic accidents have a stochastic character, therefore randomness is also present, and the interplay usually hardly unforeseeable circumstances from the outside environment, as well as the inscrutability of behaviour other participant’s road traffic. A large share of the creation accidents has chauffeurs of road vehicles with their ruthlessness,
lack of foresight, aggressiveness and the driving hazard [5].

The most vulnerable participants of road traffic are pedestrians, and that notably children and the elderly [6]. Traffic accidents have a stochastic character and therefore they are caused by randomness and interplay of usually difficult to predict circumstances from the surrounding environment, as well as the unpredictability of the behaviour of other road users. Drivers of road vehicles also have a large share in the occurrence of traffic accidents due to their recklessness, insufficient foresight, aggressiveness and hazardous driving style [7].

The age distribution of drivers with high accident tendency is mainly concentrated in the age group of 18 to 30 years. The main accident causation is the driver’s illegal driving behaviours, such as robbing road priority and overtaking, and these accidents usually occurred in rush hours. From the perspective of psychological characteristics, young people have strong aggressive psychology, blind self-confidence, and possible expectation imbalance [8].

### 3. Results of Research

The subject of this research is the only traffic accidents in road transport. Road traffic accidents include accidents causing property damage and injuries. A traffic accident is usually a direct consequence of the failure of one or more of the three interacting elements:

1. Vehicle safety.
2. Safety of road and its surroundings.
3. Required behaviour of road users.

Specifically, the following root causes have been largely attributed to the occurrence of traffic accidents in the long run:

- Incorrect driving style.
- Excessive driving speed.
- Incorrect prevention.
- Non-preference for driving, etc.

It is also necessary to draw attention to newer causes of traffic accidents which are caused by driver behaviour, or are caused by the provision of changes and rules which are not accepted by drivers for various, possibly unintentional reasons:

- Failure to control high-performance motor vehicles by drivers with short of insufficient driving experience;
- Expressions of aggression towards other road users (often derived from the strength and brand of their motor vehicle);
- Not paying attention, not concentrating on driving, distracting (e.g. handling built-in audio systems, using mobile phones while driving, large-scale advertising on roads with non-traffic issues, etc.);
- The effect of new legal provisions in the rules of the road, etc.

Reducing traffic accidents requires knowledge and analysis of the aspects behind the occurrence. This cannot be possible without appropriate statistical monitoring and processing of traffic accident data.

The road accident data are necessary not only for statistical analysis in setting priority targets but also for in-depth study in identifying the contributory factors to have a better understanding of the chain-of-events [9]. The collection and use of accurate and comprehensive data related to road accidents are very important to road safety management [10].

Table 1 provides an overview of the development of traffic accidents in the Slovak Republic for the period 2004 – 2018 by type of accident.

<table>
<thead>
<tr>
<th>Accident type</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic accidents together</td>
<td>6123</td>
<td>5999</td>
<td>6204</td>
<td>6107</td>
<td>5900</td>
<td>2598</td>
<td>2161</td>
<td>1500</td>
</tr>
<tr>
<td>Of which: death</td>
<td>531</td>
<td>492</td>
<td>519</td>
<td>568</td>
<td>509</td>
<td>303</td>
<td>319</td>
<td>294</td>
</tr>
<tr>
<td>Serious injury</td>
<td>1758</td>
<td>1625</td>
<td>1659</td>
<td>1650</td>
<td>1471</td>
<td>1141</td>
<td>1045</td>
<td>1042</td>
</tr>
<tr>
<td>Slight injury</td>
<td>6154</td>
<td>5786</td>
<td>5810</td>
<td>6282</td>
<td>6363</td>
<td>5021</td>
<td>5206</td>
<td>4439</td>
</tr>
<tr>
<td>Material damage</td>
<td>5279</td>
<td>5208</td>
<td>5405</td>
<td>5257</td>
<td>5066</td>
<td>1952</td>
<td>2077</td>
<td>1431</td>
</tr>
<tr>
<td>Of which: in the village</td>
<td>4403</td>
<td>4339</td>
<td>4545</td>
<td>4445</td>
<td>4293</td>
<td>1776</td>
<td>1466</td>
<td>1046</td>
</tr>
<tr>
<td>Outside the village</td>
<td>1719</td>
<td>1659</td>
<td>1658</td>
<td>1662</td>
<td>1607</td>
<td>8228</td>
<td>6943</td>
<td>4537</td>
</tr>
<tr>
<td>Accident type</td>
<td>2012</td>
<td>2013</td>
<td>2014</td>
<td>2015</td>
<td>2016</td>
<td>2017</td>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>Traffic accidents together</td>
<td>1394</td>
<td>1358</td>
<td>1330</td>
<td>1354</td>
<td>1352</td>
<td>1401</td>
<td>1390</td>
<td></td>
</tr>
<tr>
<td>Of which: death</td>
<td>264</td>
<td>206</td>
<td>229</td>
<td>250</td>
<td>226</td>
<td>222</td>
<td>212</td>
<td></td>
</tr>
<tr>
<td>Serious injury</td>
<td>1015</td>
<td>953</td>
<td>967</td>
<td>1004</td>
<td>941</td>
<td>1002</td>
<td>1104</td>
<td></td>
</tr>
<tr>
<td>Slight injury</td>
<td>4091</td>
<td>3954</td>
<td>4195</td>
<td>4248</td>
<td>4435</td>
<td>4414</td>
<td>4373</td>
<td></td>
</tr>
<tr>
<td>Material damage</td>
<td>1324</td>
<td>1293</td>
<td>1265</td>
<td>1282</td>
<td>1281</td>
<td>1321</td>
<td>1311</td>
<td></td>
</tr>
<tr>
<td>Of which: in the village</td>
<td>9809</td>
<td>9623</td>
<td>9744</td>
<td>9835</td>
<td>9911</td>
<td>1029</td>
<td>1026</td>
<td></td>
</tr>
<tr>
<td>Outside the village</td>
<td>4136</td>
<td>3963</td>
<td>3563</td>
<td>3712</td>
<td>3611</td>
<td>3719</td>
<td>3639</td>
<td></td>
</tr>
</tbody>
</table>
In 2009, there were fundamental changes in the legislation (classification of traffic accidents) which was significantly reflected in a decrease in traffic accidents and statistical monitoring. Part of the traffic accidents began to be categorized as damage events. Based on the above facts, the basic characteristics of the statistical set covering traffic accidents from 2009 to 2018 were quantified using descriptive statistics indicators (Table 2).

<table>
<thead>
<tr>
<th>Accident type</th>
<th>Arithmetic Mean</th>
<th>Median</th>
<th>Standard deviation</th>
<th>Variation range</th>
<th>Variation coefficient</th>
<th>Geometric Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>253</td>
<td>240</td>
<td>38</td>
<td>113</td>
<td>0,1525</td>
<td>250</td>
</tr>
<tr>
<td>Serious injury</td>
<td>1021</td>
<td>1010</td>
<td>61</td>
<td>200</td>
<td>0,0595</td>
<td>1020</td>
</tr>
<tr>
<td>Slight injury</td>
<td>4438</td>
<td>4394</td>
<td>372</td>
<td>1252</td>
<td>0,0838</td>
<td>4423</td>
</tr>
</tbody>
</table>

Variability rates indicate a relatively stable development in all types of traffic accidents in the period 2009 - 2018. Subsequently, the correlation dependence with the application of Pearson’s correlation coefficient (Table 3) between the type of accident and three selected quantitative indicators (number of registered drivers, number of motor vehicles and the total length of road infrastructure) was investigated.

<table>
<thead>
<tr>
<th>Accident type</th>
<th>Number of registered drivers</th>
<th>Number of motor vehicles</th>
<th>The total length of road infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>-0,8401</td>
<td>-0,8194</td>
<td>-0,3028</td>
</tr>
<tr>
<td>Serious injury</td>
<td>-0,3625</td>
<td>-0,2849</td>
<td>-0,0261</td>
</tr>
<tr>
<td>Slight injury</td>
<td>-0,5210</td>
<td>-0,4689</td>
<td>-0,2350</td>
</tr>
</tbody>
</table>

In all cases, a negative correlation was confirmed. Despite the fact that the number of registered drivers and motor vehicles has been increasing year-on-year for a long time, there is no relative increase in traffic accidents. It is clear from the results of the analysis that the road user and his behaviour have a fundamental influence on the traffic accident.

The use of time series is extremely important, especially for the needs of implementing forecasts for the future. There are several models for time series analysis and prediction. A model apparatus can quantify forecasts of future development by existing technical tools for time series analysis. One of the modern ways of time series analysis is the Box-Jenkins methodology. Its principle is a stochastic concept of modelling a random component of a time series. The ARIMA (The Autoregressive Integrated Moving Average Model) and SARIMA (The Seasonal Autoregressive Integrated Moving Average Model) are used for the basic linear models of time series within the Box-Jenkins methodology.

Time series that are the subject of our research (fatal traffic accidents, traffic accidents with a serious injury, and traffic accidents with slight injury) is non-stationary with the trend. Individual fluctuations are not regular; therefore, they cannot be attributed to seasonality.

<table>
<thead>
<tr>
<th>ARIMA (p, d, q)</th>
<th>MAPE value</th>
<th>MAPE value</th>
<th>MAPE value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARIMA (1, 0, 0)</td>
<td>15.160</td>
<td>8.032</td>
<td>7.221</td>
</tr>
<tr>
<td>ARIMA (0, 1, 0)</td>
<td>12.742</td>
<td>7.093</td>
<td>6.736</td>
</tr>
<tr>
<td>ARIMA (0, 0, 1)</td>
<td>26.000</td>
<td>12.677</td>
<td>11.610</td>
</tr>
<tr>
<td>ARIMA (1, 1, 1)</td>
<td>12.856</td>
<td>6.439</td>
<td>6.917</td>
</tr>
<tr>
<td>ARIMA (1, 0, 1)</td>
<td>16.090</td>
<td>7.387</td>
<td>7.234</td>
</tr>
<tr>
<td>ARIMA (1, 1, 1)</td>
<td>13.108</td>
<td>6.439</td>
<td>7.011</td>
</tr>
<tr>
<td>ARIMA (1, 1, 2)</td>
<td>13.571</td>
<td>6.268</td>
<td>6.764</td>
</tr>
<tr>
<td>ARIMA (0, 2, 2)</td>
<td>15.166</td>
<td>6.156</td>
<td>7.143</td>
</tr>
<tr>
<td>ARIMA (2, 1, 0)</td>
<td>13.819</td>
<td>6.517</td>
<td>6.892</td>
</tr>
<tr>
<td>ARIMA (2, 0, 0)</td>
<td>15.868</td>
<td>7.438</td>
<td>7.237</td>
</tr>
<tr>
<td>ARIMA (2, 2, 2)</td>
<td>15.242</td>
<td>5.799</td>
<td>7.403</td>
</tr>
</tbody>
</table>

Based on the characteristics of the time series we used the ARIMA model. There are several types of ARIMA models. Due to the relatively short time series (only 15 years), it is not possible to unambiguously determine which type of ARIMA model is the most suitable. For this reason, we tested the most commonly used ARIMA models without a seasonal component with a constant, and then we selected the most suitable model based on the smallest MAPE (mean absolute percentage error) value (Table 4). Other models with a different combination of parameters are even less suitable due to the value of MAPE in terms of accuracy and fulfillment of the required assumptions. The forecast for all
three variables was made for the years 2019-2023. The figures contains also UCL and LCL (upper and lower control limits).

The results of the time series forecast for the fatal traffic accidents (deaths) are shown in Table 5 and Fig. 1. MAPE value is relatively high (12.742) which represents a relatively high deviation. Based on the forecast, we can see a declining trend that mimics the efforts of the European Union to reduce fatal accidents.

<table>
<thead>
<tr>
<th>Model</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death-Model_ARIMA (0, 1, 0)</td>
<td>189</td>
<td>166</td>
<td>144</td>
<td>121</td>
<td>98</td>
</tr>
<tr>
<td>UCL</td>
<td>323</td>
<td>356</td>
<td>376</td>
<td>389</td>
<td>398</td>
</tr>
<tr>
<td>LCL</td>
<td>55</td>
<td>-23</td>
<td>-89</td>
<td>-147</td>
<td>-202</td>
</tr>
</tbody>
</table>

Fig. 1 Forecast of fatal accidents

The results of the time series for traffic accidents with serious injury are shown in Table 6 and Fig. 2. MAPE value is at a satisfactory level (5.799) which is an acceptable deviation. Based on the forecast, we observe a growing trend. The growing number of accidents with serious injuries can be justified by the change in the structure of accidents in terms of their severity. Development of new elements of active and passive safety, improving infrastructure and the implementation of legal norms in the field of transport mitigate the consequences of traffic accidents that would otherwise end tragically, with death.

<table>
<thead>
<tr>
<th>Model</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serious_injury-Model_ARIMA (2, 2, 2)</td>
<td>1171</td>
<td>1214</td>
<td>1287</td>
<td>1408</td>
<td>1549</td>
</tr>
<tr>
<td>UCL</td>
<td>1384</td>
<td>1603</td>
<td>1751</td>
<td>1898</td>
<td>2069</td>
</tr>
<tr>
<td>LCL</td>
<td>958</td>
<td>826</td>
<td>824</td>
<td>919</td>
<td>1030</td>
</tr>
</tbody>
</table>

Fig. 2 Forecast of traffic accidents with serious injuries

The results of the time series for the traffic accidents with slight injury are shown in Table 7 and Fig. 3. MAPE value is at a satisfactory level (6.736) which is an acceptable deviation. Based on the forecast, we observe a slightly declining trend which copies the efforts of the European Union to reduce traffic accidents.
Table 7

Forecast of traffic accidents with slight injuries

<table>
<thead>
<tr>
<th>Model</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight_injury-Model_1</td>
<td>4246</td>
<td>4119</td>
<td>3991</td>
<td>3864</td>
<td>3737</td>
</tr>
<tr>
<td>Forecast</td>
<td>4246</td>
<td>4119</td>
<td>3991</td>
<td>3864</td>
<td>3737</td>
</tr>
<tr>
<td>UCL</td>
<td>5248</td>
<td>5537</td>
<td>5728</td>
<td>5869</td>
<td>5979</td>
</tr>
<tr>
<td>LCL</td>
<td>3243</td>
<td>2701</td>
<td>2255</td>
<td>1859</td>
<td>1495</td>
</tr>
</tbody>
</table>

Fig. 3 Forecast of traffic accidents with slight injuries

Despite all the limiting facts (short time series, MAPE values), we consider the results of this forecast to be satisfactory. Our effort was not to capture the forecast in the long term (more than 5 years) because there are turbulent changes in many areas that affect the development of traffic accidents, e.g. change of legal norms, constructions of new infrastructure, degree of motorization, development and implementation of new technologies in the field of passive and active safety, autonomous transport, human factor, etc.

4. Conclusions

Based on the results of the research, we can state that a significant determinant influencing traffic accidents is the human factor. The results of the correlation analysis showed a negative correlation between the other evaluated factors (infrastructure, number of registered drivers, and number of motor vehicles). The prognostic part of the research using ARIMA models showed a declining trend in deaths and accidents with slight injuries. On the contrary, an increase in accidents with serious injuries can be expected in the next 5 years.

The EU’s long-term goals for transport safety and reducing road accidents are highly ambitious. In 2050, there is an interest in approaching zero mortality in connection with traffic accidents (“Vision Zero”) and the same should be achieved for serious injuries. New interim targets have been defined of reducing the number of road deaths by 50% between 2020 and 2030 as well as reducing the number as serious injuries by 50% in the same period. Several institutions all over the world are currently working on transport security. It is a very often discussed the topic with a multidisciplinary character involving several sectors to meet planned indicators.

References

The Effect of the Propeller Shaft Torsional Vibrations on the Accuracy of the Power Measurement

R. Indrikons

Latvian Maritime Academy, 12 k – 1, Flotes Street, Riga, Latvia, E-mail: rihards1940@inbox.lv

Abstract

The paper provides a simplified method for the calculation of torque oscillation amplitudes of an internal combustion engine and investigates how torsional oscillations affect the accuracy of the results of the torque measurement carried by a rotating shaft when the calculations are based on non-contact measurements of the twist angle of the two shaft sections. It has been found that using only two shaft-mounted marks can lead to error to several tens of per cents even in multi-cylinder engines. Recommendations for reducing this error are given.

KEY WORDS: torsional oscillations, twist angle, torque

1. Introduction

The economics, reliability and service life of a ship's engine depend to a large extent on the operating mode selected. Systematic diagnostics of the engine and control of operating parameters during the hike and analysis of the obtained data enable us to find the optimum operating modes in different shipping conditions.

The operating mode of the main engine of the ship depends on the type of ship, the conditions of navigation and the type of power supply to the engine. Typically, the power of a diesel engine is supplied to the propeller by a propeller shaft. During operation, the rotation frequency and torque applied to the propeller may change even at the same speed controller position. Such changes may be caused by the conditions of navigation as well as by the "overgrowth" of the underwater part of the ship and damage to the propeller blades and engine.

Therefore, it is expedient to periodically monitor the actual torque and therefore the power transmitted by the shaft during the voyage. The rotation frequency of the propeller is measured by tachometers of various designs, but various methods of indirect measurement are used to measure torque.

One of the methods for determining the torque is based on the measurement of the twist angle between two slits of the rotating shaft. Knowing the shaft stiffness between these slits, it is not difficult to calculate the torque. Twist angles are often measured according to the diagram shown in Figure 1, where 1 and 2 are laser beam reflecting marks, 3 and 4 - beam generators and receivers [1].

[Diagram of equipment for measuring the torsion angle]

As soon as the leading edge of sign 2 crosses the adapter beam 4, a timer is started. When the leading edge of the sign 1 crosses the beam 3 of the adapter, the time \( t_1 \) is fixed and the timer is restarted until the 4 edge of the adapter intersects the leading edges of the tag 2 again, recording the time \( t_2 \). If the shaft rotates evenly then angle \( \varphi \) may be determined by the formula:

\[
\varphi = 2\pi \frac{t_1}{t_1 + t_2}.
\]

First, the angle \( \varphi_0 \) between the marks on the unloaded shaft is determined. The shaft is then loaded with the desired torque and the angle \( \varphi_1 \) is set. The angle increases \( \Delta \varphi = \varphi_1 - \varphi_0 \) is proportional to the torque:

\[
T = c \cdot \Delta \varphi, \tag{1}
\]

where \( c \) - stiffness of the shaft between marks 1 and 3.
Diesel-powered propeller shafts are loaded with periodically varying engine torque, which is determined by rotational cylinder pressure and a discrete number of cylinders. Also, the propeller resistance torque changes during one turn. These periodic alternating forces cause the spindle to oscillate, resulting in a twist angle $\Delta \varphi$ is a periodic function of time $t$:

$$\Delta \varphi = \Delta \varphi_m + \Delta \varphi_r,$$

were the induced deviation of the torsional oscillation from $\Delta \varphi_m$ is given by the formula:

$$\Delta \varphi_r = \Delta \varphi_{a1} \cdot \sin(p_1 t + \delta_1) + \Delta \varphi_{a2} \cdot \sin(p_2 t + \delta_2),$$

were, $\Delta \varphi_{a1}$ and $\Delta \varphi_{a2}$ depend on both the ratio of the cyclically varying torque frequencies $p_1$ and $p_2$ to the spindle oscillation frequency $k$, as well as the engine torque oscillation amplitude $T_{a1}$ and the propeller impedance oscillation amplitude $T_{a2}$.

2. Calculation of the Engine Torque Oscillation Amplitude

Determine the torque $T$ on the crank so that its power is equal to the power of the gas pressure on the piston. So then:

$$\frac{\pi \cdot d^2}{4} \cdot p \cdot v = T \cdot \omega.$$

For the calculation of piston speed we will use a simplified formula (less than 1% error):

$$v = r \cdot \omega \left( \sin \beta + \frac{r}{2l} \sin 2\beta \right),$$

so

$$T = \frac{\pi \cdot d^2}{4} \cdot p \cdot r \cdot \omega \left( \sin \beta + \frac{r}{2l} \sin 2\beta \right).$$

Indicator charts for marine slow-speed two-stroke diesel engines are quite similar, only the scales differ. Further suppose that the cylinder pressure changes according to the indicator diagram for B&W S60ME-C8.2-TII engine constructed in LMA 2018 graduate E. Ziebergs diploma project [2].

The graph of the torque $T$ change law is shown in Fig. 3 with a red line.

![Fig. 2 Schematic of the piston mechanism: 1 – piston with diameter $d$; 2 – connecting-rod with length $l$; 3 – crank with length $r$](image)

![Fig. 3 Torque depending on the angle of rotation of the crankshaft in a two-stroke diesel engine; $T^*$ – graph of approximation function; $T$ – graph of the exact relationship](image)
Let us approximate the change of the torque as a function of the shaft rotation angle $\beta$ during the piston downward movement:

$$T^* = a_1 \cdot \beta^b \cdot e^{c_1/\beta}$$

and during movement of the piston up with the function

$$T^* = -a_2 \cdot (2\pi - \beta)^b \cdot e^{c_2/(2\pi - \beta)}$$

The values of the coefficients $a_1, a_2, b_1, b_2, c_1$ and $c_2$ should be chosen so that the graph of the function is as close as possible to the graph of the calculated function. When searching, we find the following coefficient values:

$$a_1 = 10000 \text{ kNm}, a_2 = 5000 \text{ kNm}, b_1 = b_2 = 0.23 \pi, c_1 = c_2 = -2.30.$$ 

In this case, the approximating functions are:

$$T^* = a \cdot \beta^{0.23\pi} \cdot e^{-2.3\beta}, \text{ if } \beta \leq \pi$$

$$T^* = -0.5a \cdot (2\pi - \beta)^{0.23\pi} \cdot e^{-2.3(2\pi - \beta)}, \text{ if } \beta > \pi.$$

The graph of the approximation function at $a = 10000$ kNm is shown in Fig. 4 with a blue line.

![Graphs of approximation functions for different cylinder numbers](image-url)
In multi-cylinder engines, the work strokes of the individual cylinders during a single crankshaft revolution, usually follows the same time intervals. Therefore, we will look at the total torque by summing the torque graphs of the individual cylinders, taking into account their time shift. The graph of the approximation function at $a = 1$ kNm for the various cylinder numbers is shown in Figure 4, which shows that the ratio of the torque amplitude $T'_a$ to its mean value $T'_m$ varies from 1.29 for a five-cylinder engine to 0.24 for a twelve-cylinder engine.

3. Experimental Determination of Torque

The equipment shown in Fig. 1 can measure $\Delta \phi$ at each shaft revolution, but engine power is determined by the average torque:

$$T_m = c \cdot \Delta \phi_m .$$

The variable component of the twist angle is caused by both the periodically varying torque that changes twice as much on a two-stroke engine as a cylinder and twice as much on a four-stroke engine as well as the thrust of a propeller that changes as many times as a propeller are the blades. The ratio of the amplitudes of the twisted angles caused by amplitude of twisted torque to the twisted angle caused by average twisted torque is calculated by the formulas

$$\frac{\Delta \phi_{\text{tw}}}{\Delta \phi_m} = \gamma_1 \frac{T_{\text{tw}}}{T_m} ; \quad \frac{\Delta \phi_{\text{tw}}}{\Delta \phi_m} = \gamma_2 \frac{T_{\text{tw}}}{T_m} ;$$

where the oscillation amplitude growth factors $\gamma_1$, $\gamma_2$ depend on the ratio of the periodically varying torque frequencies of the engine and the shaft to the lowest frequency of the torsional self-oscillation, which is usually in the operating range of revolutions. Rated speeds are usually 2 to 3 times the critical (resonance) speed and therefore have coefficients are greater than 0.11.

Fig. 5 shows a graph of total torque oscillation amplitude $\frac{\Delta \phi_{\text{tw}}}{\Delta \phi_m}$ for a single revolution of shaft for a 7-cylinder two-stroke diesel engine and 4-blade propeller with a torque amplitude 0.6 from average amplitude [3], assuming: $\delta_1 = \delta_2 = 0$ and $\gamma_1 = \gamma_2 = 0.11$.

$$\Delta \phi_m = \Delta \phi - \Delta \phi_{\text{tw}} ,$$

where from:

$$\Delta \phi = \frac{\Delta \phi_{\text{tw}}}{1 + \frac{\Delta \phi_{\text{tw}}}{\Delta \phi_m}} .$$

During power measurements, it is not possible to predict at what phase of the variable component the sign will
pass along the adapter. Since the number of cylinders and the number of propeller blades are integers, this phase will not change throughout the measurement and $\Delta \phi_T$ will remain constant. It can be seen from the graph in Fig. 5 and formula (5) that $\Delta \phi_m$ and $T_m$, respectively, can only be determined with an accuracy of $\pm 15\%$, which is not satisfactory. It should be noted that the potential error nears the resonance speed increases significantly.

4. Possibilities for Reducing Torque Detection Errors

Twisting angle reading error due to torsional oscillation can be significantly reduced by using twice the number of reflecting marks as the number of cylinders instead of one reflecting mark $l$ (Fig. 1). By placing these signs all around the circle at equal distances from each other, you can find the displacement of each sign $\Delta \phi_i$.

For each $\Delta \phi_i$, the corresponding $\Delta \phi_{mi}$ can be found by the formula (5) and for the true $\Delta \phi_m$, take the arithmetic mean of all $\Delta \phi_{mi}$:

$$
\Delta \phi_m = \frac{1}{2n} \sum_{i=1}^{2n} \Delta \phi_{mi} = \frac{1}{2n} \sum_{i=1}^{2n} (\Delta \phi_i - \Delta \phi_T) = \frac{1}{2n} \sum_{i=1}^{2n} \Delta \phi_i - \frac{1}{2n} \sum_{i=1}^{2n} \Delta \phi_T,
$$

where $n$ – the number of engine cylinders.

Since periodically changing twist angle at one revolution has exactly $n$ maximums and also $n$ minimums (Fig. 5), we conclude that the mean deviation of the spin oscillation from $\Delta \phi_m$:

$$
\Delta \phi_{im} = \frac{1}{2n} \sum_{i=1}^{2n} \Delta \phi_T,
$$

is quite tiny. A graph of its changes is shown in Fig. 6. Thus calculating $\Delta \phi_m$ by the formula:

$$
\Delta \phi_m \approx \frac{1}{2n} \sum_{i=1}^{2n} \Delta \phi_i,
$$

the error will not exceed 0.15%, which is perfectly sufficient accuracy.

5. Conclusions

The accuracy of the measurement of the torsion angle of a rotating shaft driven by an internal combustion engine is greatly influenced by the vibrations of the shaft torsion. If the torque angle is incorrectly determined, the calculation of the power transmitted by the shaft will also be inaccurate. The largest error can occur if the position of each shaft section is fixed with only one mark on the shaft during one revolution. To increase accuracy, several marks must be affixed to the shaft in each section. The error will be smallest if twice as many marks as the number of engine cylinders are symmetrically placed in each section.

References

The Long Journeys Impact on Quality Parameters of Engine Oils in IVECO CROSSWAY Buses with CR Diesel Engines

P. Lukášik¹, M. Marko², P. Droppa³, M. Marchevka⁴

¹Armed Forces Academy of Gen. M. R. Štefánik, Department of Mechanical Engineering, Demänová 393, 031 06 Liptovský Mikuláš, Slovak Republic, E-mail: pavol.lukasik@aos.sk
²Armed Forces Academy of Gen. M. R. Štefánik, Department of Mechanical Engineering, Demänová 393, 031 06 Liptovský Mikuláš, Certified Tribotechnician II, Member of board of Slovak Society for Tribology and Tribotechnics (SSTT), Kocelova č.15, 815 94 Bratislava, Slovak Republic, E-mail: miroslav.marko@aos.sk, mikro_makro@pobox.sk
³Armed Forces Academy of Gen. M. R. Štefánik, Department of Mechanical Engineering, Demänová 393, 031 06 Liptovský Mikuláš, Slovak Republic, E-mail: peter.droppa@aos.sk
⁴Armed Forces Academy of Gen. M. R. Štefánik, Department of Safety and Defense, Demänová 393, 031 06 Liptovský Mikuláš, Slovak Republic, E-mail: martin.marchevka@mil.sk

Abstract

This article deals with engine oils (EO) degradation of Petronas Urania FE LS, 5W-30 type in Iveco Crossway buses (Figs. 5 and 6), effects of engine oil degrading factors in a matter of operationally influenced selected parameters. The vehicles were operated in long - term one - off modes (long distance driving) on roads - approximately 95% and also in a so called „Go-Stop“ intermitted operation mode - approximately 5%. The engine oils were measured tribodiagnostically with tribodiagnostic devices SpectroVisc 3050, Spectro Q 1000 Fluidscan and Ferro Check 2000. Due to the low values of ferro - particles (26Fe55, 845 - Ferrum; 27Co58, 933 - Cobalt; 28Ni58, 693 - Niccolum), no measurement was performed on the Fero chart tribodiagnostic set. The article points to the change of monitored parameters of motor oils in vehicles. Samples of used motor oils from buses were compared with unused reference motor oils. It was the monitoring of one oil fill. No oil change was made between measurements.

KEY WORDS: durability standard, kinematic viscosity, TBN - total base number, carbon residue, oxidation, nitration, sulfation, water content, AW additives, ferro - particles

1. Introduction

Criteria for evaluating the properties of motor oil:

- LONG DISTANCE DRIVING - long-term driving modes. This is understood as operation during long journeys on paved roads and with a moderate load on the vehicle. By this is meant a long time operation in at least 60% to 70 % cases of individual rides, where the coolant is heated to 80°C - 90°C, the engine oil is heated to 90°C - 130°C for each drive for approximately 1 hour or more [5].
- CITY CYCLE or „Go - Stop“ operation mode: This means short cold engine trips, coolant temperatures up to 70°C, engine oil temperatures up to 60°C - 70°C, travel time approximately 20 minutes. Short - term start-up of a vehicle´s engine, off - road driving, driving with the maximum load of the vehicle, or driving in winter conditions may have a similar character [5].
- STANDARD OPERATION is understood to be the operation of the vehicle as a combination of „Go - Stop“ type (about 20% to 30% of the total number of journeys) and long journeys lasting at least 1 hour or more when the engine oil overheats to 80°C - 130°C (about 70% - 80% of the total number of trips), during the life of the engine oil in the vehicle [5].

2. Qualitative Properties of Oil

Appearance (comparison of clarity, shine, smell and turbidity): According to own methodology (practical experience and expertise) determine meeting demanded conditions or not. Do not allow turbidity - matte surface when light is reflected. [1]

Viscosity index: Dependence of oil flow ability on temperature. The viscosity index rate determines that lubrication is sufficient under operating conditions. Allow the engine oil to operate only within a viscosity index of ± 15 points from the reference sample. [1]

Flash point (basic parameter for lubrication of piston rings especially in the exhaust phase):
Do not allow the engine oil to operate when the flash point drops below 180° C for the diesel engine. [1]

Glycol: [%], glycol content (Ethylene Glycol - C2H6O2, or Propylene Glycol - C3H8O2) is in the engine oil non - permissible. Glycol causes separation of the additive in the motor oil and thickening of the engine oil. [3]

Additives: [%], total engine oil additives. Engine oil must be usable in working parts of the engine under all conditions. Ingredients are chemicals of complicated composition. They improve the performance of the base oil. They
slow down the aging and degradation of the engine oil (Figs. 1 and 2). They meet the demanding conditions of modern engines. Reducing the content of additives below 50% is unacceptable. [4]

Figs. 1 and 2 An illustration of the effect of glycols on engine oil

Wear elements (concentration of elements - assessment of working areas wear condition): Assess wear elements by performing statistical observations and comparing values for the same engine types with a focus on values in accordance with ISO 14830 [5].

Ferro-particles content: \((^{26}\text{Fe}_{55,845}, ^{57}\text{Co}_{933}, ^{28}\text{Ni}_{693})\) - Measured by a laboratory tribodiagnostic instrument – Ferro Check 2000 Series: Ferromagnetic metals are metals with magnetic properties. Their occurrence in engine oils indicates wear of the respective engine contact surfaces. For the assessment of motor oils, the following limitation has been set for Ferro - particles by P - VV4 [1]:
- Ferro Check 2000 is set to an interface of 1.000 ppm;
- Quantity \(<0 \text{ ppm} - 30 \text{ ppm}\>\) Ferro - particles occurrence;
- Quantity \(<30 \text{ ppm} - 70 \text{ ppm}\>\) Increased occurrence of ferro – particles;
- Quantity \(<70 \text{ ppm} - 100 \text{ ppm}\>\) Hazardous amount of ferro - particles occurrence;
- Quantity \(<101 \text{ ppm and more}\>\) Intolerable amount of ferro - particles occurrence.

Note: 1 ppm = 0.0001%

Engine oil is a complex fluid and has characteristics standards assessment:

Kinematic viscosity: Is the primary and essential property for the suitability of motor oil in a vehicle engine. Motor oil is only suitable for viscosity in the range ± 20% of the reference sample and the manufacturer's motor oil recommendation [5].

TBN: Parameter, which is used to assess the ability to dissolve acid sludge, its level also reflects the life of motor oil. Do not allow the operation of motor oil when the TBN value decreases by more than compared to the value of the reference sample and the manufacturer's motor oil recommendation [5].

Soot: \([\% \text{ w/t}]\), Carbon content (CCT), compared in relation to kinematic viscosity, may not be increased to 20% [5].

Oxidation: \([\text{abs/ 01}]\), (longevity and foaming), do not allow engine oil to run, when the antioxidant content is reduced by more than 50% [5].

Nitration: \([\text{abs/ cm}]\), is the introduction of one or more groups of \(\text{NO}_2\) in to organic compounds. It is the conversion of ammonium salts into nitrates by the action of bacteria. It causes the breakdown of base oil and additives. It is a negative parameter in engine oil. The forbidden limit is above 30 \([\text{abs/ 01}]\) [5].

Sulfation: \([\text{abs/ cm}]\), is the process forming sulfates. Sulfates are salts of sulfuric acid, sulfates. It causes the breakdown of base oil and additives. It is a negative parameter in engine oil. The forbidden limit is above 30 \([\text{abs/01}]\) [5].

Water content: Has an impact particularly on corrosion and foaming. Motor oil is unsatisfactory when the water content increases to more than 0.5% of its volume [5].

3. Research Methodology

URANIA FE 5W-30 (Figs. 3 and 4) is engine oil, partly synthetic based, for turbocharged engine trucks of all types and powers. It responds in a new way to the most demanding requirements of heavy vehicle designers and users, while guaranteeing a reduction in the number of maintenance stops and an extended replacement interval to the longest possible extent.

Figs. 3 and 4 Reference oil Petronas Urania FE LS

The object of the research was a bus Iveco Crossway (Fig. 5). The engine of this bus has been presented in Fig. 6.
Oil sampling and tribodiagnostic laboratory are shown in Figs. 7-9.

Tribodiagnostic instruments for measuring the quality parameters [2] of lubricants are shown in Figs. 10 and 11.

Examples of measured values are shown in Tables 1-2.

### Table 1

<table>
<thead>
<tr>
<th>Oil parameters</th>
<th>Measuring No. 1</th>
<th>Measuring No. 2</th>
<th>Measuring No. 3</th>
<th>Ø</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity 40°C (cSt)</td>
<td>84.80</td>
<td>88.0</td>
<td>83.10</td>
<td>85.57</td>
</tr>
<tr>
<td>Kinematic viscosity 100°C (cSt)</td>
<td>11.60</td>
<td>12.00</td>
<td>11.40</td>
<td>11.67</td>
</tr>
<tr>
<td>Difference from the reference sample (%)</td>
<td>at 40°C = -17.72%</td>
<td>at 100°C = -10.51%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2

Example of measured values

<table>
<thead>
<tr>
<th>Oil parameters</th>
<th>Measured value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW additives (%)</td>
<td>94.00</td>
<td>96.00</td>
</tr>
<tr>
<td>Glycol (%)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Nitrilation (abs/cm)</td>
<td>7.80</td>
<td>7.80</td>
</tr>
<tr>
<td>Oxidation (abs/0,1)</td>
<td>11.30</td>
<td>11.30</td>
</tr>
<tr>
<td>Soot (% wt)</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Sulfation (abs/0,1)</td>
<td>15.90</td>
<td>16.00</td>
</tr>
<tr>
<td>TBN (mg KOH)</td>
<td>10.40</td>
<td>10.40</td>
</tr>
<tr>
<td>Water content (ppm)</td>
<td>416.00</td>
<td>4188.00</td>
</tr>
</tbody>
</table>

Infrared spectrometry with the use of Fourier transformation (FTIR) is one of the modern methods appropriate for operating fluids identification and following determination of the physico-chemical parameters. The principle of infrared spectrometry is based on Lamber-Beer law, which has an exponential form and can be mathematically expressed as follows [6]:

\[ I = I_o \cdot e^{-\varepsilon c l} \]

where: \( I_o \) – incident radiation intensity; \( I \) – passing radiation intensity; \( \varepsilon \) – molar absorb coefficient; \( l \) – absorb medium thickness; \( c \) – concentration of the monitored substance [6].

4. Results and Discussion

Results of measuring of engine oil samples are shown in tables (Tables 3-5). It is a comparison of the Petronas Urania FE LS engine oil parameters (O-1178) in the Iveco Crossway bus engine (95% of the long drive). Measurements were performed in laboratories CMaS Žilina and AOS Liptovský Mikuláš (Figs. 7-9). The measurement was carried out using modern instruments (Figs. 10-15).
Evaluation of engine oil properties Petronas Urania FE LS 5W-30 in the IVECO Crossway bus

### Table 4

#### Measured properties

<table>
<thead>
<tr>
<th>No.</th>
<th>Property / Unit</th>
<th>REFERENCE OIL 80/20 SAE 5W-30</th>
<th>Sample No. 1</th>
<th>Sample No. 2</th>
<th>Sample No. 1 AOS-3</th>
<th>Sample No. 2 AOS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CMA5-ZA measured 31.05.2019</td>
<td>CMA5-ZA measured 31.05.2019</td>
<td>CMA5-ZA measured 22.10.2019</td>
<td>AOS LM measured 18.06.2019</td>
<td>AOS LM measured 18.06.2019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CMA5-ZA measured 31.03.2019</td>
<td>CMA5-ZA measured 31.03.2019</td>
<td>CMA5-ZA measured 31.03.2019</td>
<td>CMA5-ZA measured 31.03.2019</td>
<td>CMA5-ZA measured 31.03.2019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9,839 km from start-up</td>
<td>22,224 km from start-up</td>
<td>22,224 km from start-up</td>
<td>9,839 km from start-up</td>
<td>22,224 km from start-up</td>
</tr>
<tr>
<td></td>
<td>Worked km / Mm from oil change</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Engine oil life standard</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>80,000/2 years</td>
<td>80,000/2 years</td>
<td>80,000/2 years</td>
<td>80,000/2 years</td>
<td>80,000/2 years</td>
<td>80,000/2 years</td>
</tr>
<tr>
<td></td>
<td>Appearance of oil</td>
<td>Passes</td>
<td>Passes</td>
<td>Dark</td>
<td>Appearance of oil</td>
<td>Clear with reflection</td>
</tr>
<tr>
<td></td>
<td>IR spectrum (4000-400 cm⁻¹)</td>
<td>Record</td>
<td>Record</td>
<td>Record</td>
<td>Record</td>
<td>Record</td>
</tr>
<tr>
<td></td>
<td>Viscosity at 15 °C [kg.m⁻²]</td>
<td>855.6</td>
<td>858.8</td>
<td>859.7</td>
<td>858.8</td>
<td>859.7</td>
</tr>
<tr>
<td></td>
<td>Kinematic viscosity at 40 °C [mm².s⁻¹]</td>
<td>74.43</td>
<td>74.47</td>
<td>74.57</td>
<td>74.47</td>
<td>74.57</td>
</tr>
<tr>
<td></td>
<td>Kinematic viscosity at 100 °C [mm².s⁻¹]</td>
<td>11.99</td>
<td>11.99</td>
<td>12.04</td>
<td>12.04</td>
<td>12.04</td>
</tr>
<tr>
<td></td>
<td>Viscosity index [index]</td>
<td>160</td>
<td>182</td>
<td>158</td>
<td>182</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>Flash point in OT according to Cleveland [°C]</td>
<td>238</td>
<td>239</td>
<td>230</td>
<td>239</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>Total base number (TBN) [mg KOH/g]</td>
<td>13.5</td>
<td>13.0</td>
<td>12.3</td>
<td>13.0</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>Carbon residue (CCT) [% w/w]</td>
<td>1.10</td>
<td>1.14</td>
<td>1.21</td>
<td>1.14</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>Pour point (PP) °C</td>
<td>-48</td>
<td>-48</td>
<td>-48</td>
<td>-48</td>
<td>-48</td>
</tr>
<tr>
<td></td>
<td>Oxidation products [A/cm]</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Nitration products [A/cm]</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Sulfation products [A/cm]</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Glycol content [%]</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td></td>
<td>Copper corrosion 3h 100 °C [class]</td>
<td>1c</td>
<td>2c</td>
<td>2c</td>
<td>2c</td>
<td>2c</td>
</tr>
<tr>
<td></td>
<td>AW additives [%]</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Table 5

<table>
<thead>
<tr>
<th>cSt</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>11.73</td>
<td>13.08</td>
<td>12.03</td>
<td>11.73</td>
</tr>
<tr>
<td>12</td>
<td>1.67</td>
<td>1.97</td>
<td>1.20</td>
<td>1.67</td>
</tr>
<tr>
<td>10</td>
<td>1.07</td>
<td>1.60</td>
<td>1.20</td>
<td>1.07</td>
</tr>
<tr>
<td>8</td>
<td>0.97</td>
<td>0.97</td>
<td>0.97</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Sample No. 1 (73/2019, taken at 9.839 km) and Sample No. 2 (194/2019, taken at 22.224 km) from IVECO Cossway, MEV 68 75 540: COMPLY for further use in service. The measured values show that the engine oil is in a very good condition and has a sufficiently large back up to the limit values of the individual monitored parameters.

5. Conclusion

Iveco Crossway buses are newly introduced vehicles for the needs of the Slovak Armed Forces. As these are new and expensive vehicles, some of them are subject to preventive tribological monitoring by CMaS Žilina and AOS L. Mikuláš. Monitoring showed, that the differences between certified measurements of CMaS Žilina and uncertified measurements within the educational process of AOS L. Mikuláš show only minor differences and are within the allowed tolerances. While maintaining the bus operation as it is up to now, it is assumed that the standard of the durability of the monitored engine oil could meet the values stated by the seller 80.000 km/2 years (note: the manufacturer MO Petronas Urania even reported values 150.000 km/2 years). The new vehicle engine and operation over predominantly long routes are critical operating factors that should be reflected in the long life of the oil fill.

Acknowledgements

The research is funded by the research project „VV-1 Design and application of tribodiagnostic methodologies for operation and maintenance of ground equipment of the Slovak Republic“.

References

1. Military Specification no. MSU-27.1/L, O-236/1, Metrology and testing institute in Žilina, Žilina, 1/2014.
5. Properties and tribodiag. of lubricants in motor operation vehicles, ULZ OS SR, Bull-12-6 Trenčín, 2014
VTOL Design for Fixed Wing UAVs

F. Škultéty¹, J. Čerňan², T. Sisák³

¹University of Zilina, Univerzitna 8215/1, Zilina, Slovak Republic, E-mail: filip.skultety@fpedas.uniza.sk
²University of Zilina, Univerzitna 8215/1, Zilina, Slovak Republic, E-mail: jozef.cernan@fpedas.uniza.sk
³University of Zilina, Univerzitna 8215/1, Zilina, Slovak Republic, E-mail: tomas.sisak@stud.uniza.sk

Abstract

The paper focuses on solving the problem of vertical take-off and landing (VTOL) of an Unmanned Aerial Vehicle (UAV) with fixed wing. The introduction describes the two most used types of UAVs, emphasizing the positive and the negative properties of the UAVs. The next chapter focusses on the design and the process of building a UAV. The following chapter is devoted to the used electronics, describing each component separately, but at the same time, describing the electronic components necessary for the VTOL. The main idea is to introduce the functioning of the sole component and the correct setting using computer software. Furthermore, there are calculations that are necessary to determine the operating values such as the speed range and the multiples for safe operations of the UAVs. These calculations are obtained computationally but also by simulation, using the XFLR5 software.

KEY WORDS: UAV, fixed wing, vertical take-off and landing, design, VTOL, XFLR5

1. Introduction

Unmanned aerial vehicles are being used more and more. Whether it's amateur UAVs for aerial photography, professional UAVs used in agriculture and geodesy, or even military remote pilot aircraft. A fast and efficient way of aerial work has become more accessible for a wider range of uses thanks to lower costs. There are various designs of UAVs [1]. They can be divided into two basic groups. Unmanned aerial vehicles with fixed wings and unmanned aerial vehicles with multi rotors. This paper is focused on the design, construction and configuration of UAVs with fixed wing and the possibility to use vertical takeoff and landing [2]. This type of UAV solves the shortcomings associated with the short range of UAVs with rotary wing and the complexity of the take-off of UAVs with fixed wing [3]. It uses only the positive properties of both types of UAVs. The paper contains the design and its construction, the individual parts of the UAV - the fuselage, the wing, the tail and control surfaces. With the electronics used, all components used in the UAV are described - motor, controller, servos, battery. A separate chapter consists of the function and settings of Pixhawk, which is an electronic component necessary for the vertical takeoff of the UAV [7]. At the end of the work are contained parameters of values of multiples and angles of approach, at which the UAV can operate during the flight. These data are obtained computationally using formulas but also simulated in the open source software XFLR5.

There are several military or experimental aircraft with the possibility of vertical takeoff and landing. When designing this UAV, the simplicity of the systems, weight and flight characteristics in the horizontal flight of the UAV was considered [4]. The principle of UAV flight is most easily described on a quadcopter, as it has four propellers and four engines on four different arms. Each of the propellers creates lift and torque at the same time. Thus, if the propeller rotates clockwise, then according to Newton's third law, the arm will tend to rotate in the opposite direction. Therefore conventional helicopters need a tail rotor. However, in the case of UAVs, two clockwise and two counterclockwise propellers are used, placed diagonally opposite each other, thus eliminating this effect. Thanks to this, the UAV can float very well on the spot. If we want to fly forward with the UAV, the front engines will reduce their speed and, conversely, the rear will increase. In the same way, the UAV also creates a tilt.

2. UAV Airframe Design and Construction

The primary role of the UAV airframe is to meet operational and strength requirements. Fig. 1 depicts the conceptual design of the UAV. The vertical take-off engines will be located on the extended fuselage arms, with the diagonals intersecting at the UAV's center of gravity. For the horizontal flight, the classic arrangement of the aircraft will be used - fuselage, wing and tail surfaces.

The fuselage is understood as a space beam, so it ensures the connection of all parts of the aircraft. It connects the wings, tail surfaces and landing gear. It also includes a power unit and the fuselage is guided by the aircraft. The fuselage must be structurally reinforced at the points of attachment of the wing. At low, subsonic speeds, the fuselage is a source of passive drag. The cross-sectional shape of the fuselage is to some extent influenced by the purpose of use. When choosing this shape for a given type of UAV, an ellipse with the same cross section in the front and rear of the fuselage was used. The fuselage length has been designed to accommodate the battery, autopilot system, receiver and controller.
When solving the problem of wing construction, there is a wide range of feasible variations of structural solutions. The wing is composed of four parts. Each part has a polystyrene core which is coated with balsa. Like the fuselage, the wing core is cut through the wing profile template at the root and the wing end profile with resistance wire. This core is reinforced by a spruce beam, the beam being used to reinforce only two inner parts. The outer wing units do not have a beam. The main parts, i.e. the inner parts of the wings, are of a simple rectangular shape and have no support to the fuselage. The main beam connects these parts and is made in one piece without changing the angle. In addition to polystyrene, the core itself also consists of a balsa leading and trailing edge. A 0.8 mm thick balsa was used as the wing shell to surface strengthen the wing. The end 400 mm long parts of the wings are similar to the main parts formed by a polystyrene core, a balsa leading and trailing edge, covered with balsa, but a spruce beam is not used. Unlike the inner parts, the end parts have a tapering character and are therefore a trapezoidal wing. For better stability around the longitudinal axis, a 20° recess was used between the main and end parts of the wing. This rebound is also used because the aircraft does not have ailerons.

In order to achieve the desired performance of the tail surfaces on the aircraft, we must choose the correct position and shape of the tail surfaces. The shape of the tail surfaces mainly determines the profile we choose. In the case of tail surfaces, a symmetrical profile is usually chosen. This profile on the horizontal stabilizer does not create any lift during the horizontal flight if the setting angle is zero. This phenomenon is desirable. The fact that no buoyancy is created does not mean that other forces do not act. Gravitational force is still present and so is resistance. This means that in horizontal flight, the resultant force will act downwards and slightly to the right. We also choose a symmetrical profile on the horizontal stabilizer. The position of the tail surfaces, i.e. their distance from the center of gravity, is chosen regarding the required controllability and stability.

3. UAV Autopilot and Electronics

Autopilot Pixhawk PX4 is an "open-source" control board designed mainly for DIY autonomous aircraft, UAVs, ships and submarines [5]. The relatively low price, availability and reliability allow the use of this control board in small UAVs. To secure the flight, Pixhawk uses sensors to determine and then evaluate the condition of the aircraft, this data is then used for stabilization or autonomous flight. For this purpose, Pixhawk uses sensors such as a gyroscope, accelerometer, magnetometer (compass) and barometer, which are already directly implemented on the board. These sensors are an integral part of proper flight. However, for maximum use, it is necessary to connect a GPS or other positioning system to Pixhawk to allow the use of all automatic or assistance modes. Furthermore, various sensors can be connected to Pixhawk, from a speed air sensor (used for accurate speed measurement, especially for UAVs with fixed airframes and VTOL) to LiDAR (obstacle avoidance). Pixhawk works on a 168 MHz 32bit STM32F427 Cortex M4 processor with 256 kB of memory. As they are "open-source" hardware, there are various copies available on the market. Control of speed controllers and motors - Most modern UAVs use AC motors for their drive, which are controlled by controllers, which receive a signal from the control unit based on evaluated data and thus change the motor speed and thus ensure a stable flight [7].

The UAVs is powered by a LiPo battery. The battery is usually connected to the system via a "power module", which supplies the Pixhawk with the appropriate voltage, and via a "power distribution board", which provides separate power for the control unit and ESC (motor power supply). The Radio Control (RC) system is designed to manually control UAVs. It consists of a transmitter and a receiver that communicate with each other. The operator uses a transmitter to send a signal to the receiver, which evaluates the operator's input, and passes this information on to the control unit, which further processes this input and thus changes the direction of flight / movement along the desired axis. Telemetry is used for remote wireless connection of the control unit and the relevant software. Thanks to this, it is possible to change the parameters of the control board, monitor flight data and the like directly during the flight [8].

Flight data storage - Pixhawk uses SD cards to record and then store flight data, these records can later be viewed in the appropriate software and evaluated. "Failsafe" is a system that provides protection and rescue of UAVs in case something stops working as it should. This function monitors the progress of the flight and, in the event of, for example, loss of signal with RC, reduction of battery voltage, automatically takes steps to prevent a fall (eg. in case of loss of UAV signal, it lands automatically).
After installing the firmware and basic settings, go to the Config tuning tab and then to the Full parameter list. Subsequently each parameter change, it is necessary to first click outside the changed parameter (e.g., on another) and then Write Parameters.

At the beginning of the Full parameter list, the _Q_ENABLE_ parameter is searched by searching to the right - This parameter is set to the value 0 at which VTOL support is disabled, changing this command to 1 enables VTOL support. We refresh the parameter list by clicking on the refresh params button, from this moment all parameters for VTOL are visible and are recognizable by starting with the character Q.

Construction type selection:
The _Q_FRAME_CLASS_ and _Q_FRAME_TYPE_ parameters are used to select the correct type of construction to be used. _Q_FRAME_CLASS_ can be:
- 1 for quad;
- 2 for hex;
- 3 for vinegar;
- 4 for octaquad;
- 5 for Y6;
- 7 for Tri;
- 10 for Tailsitter.
In this case, you need to change the value to 1 (quad).

The _Q_FRAME_TYPE_ parameter specifies the type of motor arrangement.
- 0 for plus frame;
- 1 for X frame;
- 2 for V frame;
- 3 for H frame;
- 11 for FireFly6Y6 (for Y6 only).
For this type of UAV, change to 1 (X frame).

The _Q_M_SPIN-ARM_ parameter is important for achieving the correct speed of the motors after "disarming" the VTOL, too high a value will cause the VTOL to rise into the air immediately after starting the motors (a value of 0.1 should be sufficient).

_Q_A_RAT_RLL_P_ and _Q_A_RAT_PIT_P_ these parameters are the most critical parameters when tuning VTOL, the value is set to 0.25, but it may be necessary to increase this value (increasing the value too much will result in very sharp reactions UAV and UAV will tremble overall, too low UAVs will react very slowly).

_RTL_AUTOLAND_ parameter that determines how VTOL should behave when switching to RTL mode:
- Value 0 - RTL disabled
- Value 1 - On, the UAV will go to the take-off location and land there
- Value 2 - On, the UAV will start landing immediately
As the GPS sensor will not be used in this UAV, the value 2 will be used to make VTOL land immediately. (You can set this setting for a possible signal failure (failsafe).

_FS_LONG_ACTN_ parameter determines how VTOL should behave in the case of Failsafe.
- Value 0 - Will continue in the summer
- Value 1 - switches to RTL mode
- Value 2 - starts to slide
- Value 3 - opens the parachute
Ideal for this type of UAV, the value will be 1 as it is the safest of the above options.

_Q_OPTIONS_ is a "bitmask" that determines the behavior of the VTOL function.
- Bitmask 0 - VTOL takes off like a UAV with rotating airfoils - multicopter
- Bitmask 1 - VTOL takes off like a UAV with fixed airfoils - an airplane
- Bitmask 2 - VTOL will land a UAV with fixed airfoils - an airplane
Other "bitmasks" are not important to the user as they are not relevant to the type of UAV.

4. UAV Operational Calculations

The calculations for the UAV will be based on the basic assumption that in uniform straight flight, the weight of the aircraft should be equal to the lift. All calculations will be for mid-sea level ISA conditions. Also, the calculations are intended for the configuration of aircraft. The weight of individual parts of the aircraft arises in its mass, which is located in the gravitational field of the Earth. The magnitude of such a load is determined by:
where, \( G \) (N) is the weight of the aircraft \( m \) (kg) is the mass of the aircraft \( g \) (m.s\(^{-2}\)) is the gravitational acceleration of the Earth. With a negligible change in the gravitational acceleration, the weight practically depends only on the mass. The direction of gravity is given by the direction of the Earth's gravitational acceleration.

For the UAV, a weight of 1.3 kg was determined, which is based on the sum of the individual parts of the UAV:

- fuselage without electronics - 130 g
- wings - 350 g
- tail surfaces - 50 g
- 5x ESC - speed controller 7.3 g x 5 = 36.5 g
- 5x alternating motor - 5x 55 g = 275 g
- 5x propeller -6 g x 5 = 30 g
- Pixhawk - 38 g
- 2x servos 2x15 g = 30 g
- battery - 300 g
- accessories, cabling - 60 g

\[ G = 1.3 \text{ kg} \times 9.81 \text{ m.s}^{-2} = 12.753 \text{ N} \]

Lift \((L)\) is a component of the resulting aerodynamic force in the direction of the buoyancy axis, created by the action of body and fluid motion.

\[ L = \frac{1}{2} \rho v^2 \cdot S \cdot c_L, \tag{2} \]

where \( L \) (N) is the aerodynamic lift in (m.s\(^{-1}\)) is the flow velocity, \( \rho \) (kg.m\(^{-3}\)) is the air density, \( S \) (m\(^2\)) is the reference area, \( c_L \) is the coefficient of lift.

The cruising speed of the UAV was determined to be 12 m.s\(^{-1}\). The area and lift coefficient are obtained from the analysis in the XFLR5 program. The wing area is 0.242 m\(^2\) and the lift coefficient at a angle of attack 4° is 0.642. \( L = 13,703 \text{ N} \). The calculation shows that at an angle of attack of approximately 4° of a given speed and area of the wing, the UAV will be in uniform straight flight. For comparison - calculation of lift for the zero angle of attack and subsequently for the maximum angle of attack, which was determined to be 14°. For the zero angle of attack, the CL value is 0.3043 at a speed of 12 m.s\(^{-1}\). For a maximum angle of attack of 14 °, the CL value is 1.3607 at a speed of 12 m.s\(^{-1}\). The theory expresses that drag depends on flight speed, flight altitude and the size of the drag coefficient. The resistance value is determined at uniform straight flight. The angle of attack in these conditions is 4° and the CD value corresponds to 0.017 at a speed of 12 m.s\(^{-1}\).

Flight envelope (Fig. 2) for fixed wing airplanes is specified as follows. The positive load factor must not be less than the load factor specified by the equation:

\[ 2.1 + 24.000/(W + 10,000), \tag{3} \]

where, \( W \) is maximum take-off mass in lb. Since in this case it is a low-weight UAV, according to the formula, a load factor of approximately 4.5 was obtained, but according to this rule, the positive multiple may not be greater than 3.8, so we choose \( n = 3.8 \). The negative operating multiple for prescribed turnover shall not be less than 0.4 times the positive operating multiple. The value of the minimum negative operating multiple is therefore \( n2 = -1.52 \).

The maneuvering speed (\( V_a \)) is the maximum speed at which the maximum rudder deflections can be used without exceeding the maximum permissible value of the load factor, in this case 3.8 G.

![Fig. 2 UAV flight envelope](image)
The following section focuses on the design and some characteristics of UAV airfoils in aircraft configurations. The XFLR5 software is a modeling program with which it is possible to perform certain measurements and analyzes related to the issue of different wings and their profiles [6]. In the case of the UAV wing, a profile was designed which, with its properties, largely met the requirements for the flight characteristics of the aircraft. After comparing and considering different options and types from a wide range of profiles, the shape of the profile with the type designation NACA 4412 best met these requirements.

During the flight, two basic, main forces are created and act on the aircraft, which are called lift and drag. With the help of these two quantities it is possible to derive their coefficients $C_L$ as coefficient of buoyancy and $C_D$ as coefficient of resistance. These two quantities interact with each other. Under standard conditions, there is a linear relationship between them, which in practice means that with increasing lift, the resistance also increases and vice versa. The higher the value of this proportion (the value of lift increases faster than the value of drag), the cleaner and aerodynamic the design of the aircraft. Higher lift-to-drag ratios represent an increase in fuel economy, an improvement in aircraft performance and, finally, an improvement in glide. The ratio of lift to drag coefficients can be determined by direct measurements, mathematical calculations or by subtracting the results of analyzes in a modeling program such as XFLR5. The graph of the ratio of lift and drag coefficients consists of two axes, $C_D$ is projected on the x-axis and $C_L$ is projected on the y-axis (Fig. 3).

![Fig. 3 $C_L/C_D$ graph in XFLR5](image)

The XFLR5 provides a wing modeling function for UAVs in an aircraft configuration. When entering the basic parameters of the wing, the program models the wing as shown in the figure. The span of the wing reaches the value of 1.6 meters and at the length of the chord 0.16 m and at the ends of the wing 0.12 m the program calculated the area of the wings $0.24 \text{ m}^2$. With the estimated weight of the model, the surface load of the wing will be $5.4 \text{ kg/m}^2$. The string at the root of the wing is 0.16 m long, at the ends of the wings 0.120 m. The value of the mean aerodynamic chord (M.A.C) is $0.151 \text{ m}$.

Due to the existence of different pressures above and below the wing, air flows from the lower, overpressure part, to the upper part where the pressure is lower, which is due to the shape of the profile. By assembling the vectors of the longitudinal flow velocity at the bottom of the wing and the flow velocity of the approaching air stream, we create an image of the actual flow around the wing, which is characterized by the formation of a swirling air flow at the wingtips (Fig. 4). These edge vortices gradually disappear due to the viscosity of the environment.

The effect of vortices on the UAV (Fig. 5) will be reduced by narrowing the end portions of the wings, which are not as effective as the winglets, but serve their purpose. In the case of UA flight in an airplane configuration, potential winglets would produce a greater component of harmful resistance than the induced drag component at cruising speeds without the use of induced drag reduction methods.

![Fig. 4 UAV wing design and CFD analysis](image)
Fig. 5 Final assembly of the UAV

5. Conclusions

The aim of the paper was to create a design and analysis for the construction of UAV. Unmanned aerial vehicles exist of various kinds. A completely unique UAV was chosen for the construction, which with its construction and configuration has most of the positive features. It was a design of an unmanned aerial vehicle with the possibility of vertical takeoff and landing. The calculations are used to determine the operating limits, specifically the range of speeds and multiples at which the UAV can be used safely. This type of unmanned aerial vehicle has a wide range of uses. The dimensions of the fuselage and wings are adapted to the subsequent installation of cameras or other payload that can later be used in aerial work. Preliminary flight tests have proven the functionality of this concept and reliable operation in the VTOL mode as well as in conventional flight. Further research will focus on the deployment of advanced sensors supporting big data and autonomous flights.

Acknowledgement

This paper is supported by KEGA 048ŽU-4/2020, Increasing key competencies in aircraft maintenance technology by transferring progressive methods to the learning process.

References

7. Pixhawk. [online cit.: 2020-07-22]. Available from: https://pixhawk.org/?fbclid=IwAR0L_wNxDVjQPv8pGNNlrT0593cZx4vfXwVkgQqY mB5MJDCjeE8G1_FdM
Influence of Powder Mass on Barrel’s Muzzle Vibration

P. Perun

Department of Mechanical engineering, AOS gen. M.R.Štefánika L.Mikuláš, Demänová 393, P. O. Box 9, 031 06 Liptovský Mikuláš 6, E-mail: peter.perun@aos.sk

Abstract

The displacement of the barrel’s muzzle of small caliber weapons during the shooting has a major influence on accuracy. It’s caused by the vibration of the barrel’s muzzle which is invoked by the movement of the bullet in guiding part of the small caliber’s barrel. The size of the displacement of the muzzle depends on barrel’s material, manufacturing technology of barrel, construction solution of weapon, quality and parameters of used ammo [1, 4, 5].

Analysis was performed based on experimental data. The experiment was composed of four groups of bullets with a different mass. The vibration of a barrel was measured by the Brüel & Kjær PULSE 3560 equipment. Data from the PULSE system was processed by the Fast Fourier Transform (FFT). In the next step, these data were used for calculation of a Power Spectral Density (PSD). PSD describes a distribution of power throughout a frequency spectrum.

KEY WORDS: powder mass, barrel, muzzle velocity, vibration, precision

1. Introduction

The experiment was focused on determining the effect of changes in the volume of the powder charge on the muzzle vibration of a small-caliber barrel. The barrel vibration mainly affects the accuracy of shooting. The connection with the specific weight of the powder charge and the subsequently exciting oscillation of the muzzle of the small-caliber barrel was searched. The oscillation mainly occurs by the accelerated projectile crossing through the guide part. The course of the oscillation is reflected in the resulting accuracy in the target. The logical rule should be that as the weight of the powder charge increases, the dynamics of the muzzle velocity increase too. Increasing the muzzle velocity excites higher values of barrel oscillation at the mouth.

2. Procedure for Measuring Parameters of Barrel Oscillation and Scattering within the Experiment

Four groups of 25 pieces each of 5.56 × 45 mm caliber rounds were completed. The groups weighed 1.5 g, 1.55 g, 1.6 g, 1.65 g of Lovex D073.4 nitroglycerin powder. The measurement consisted of four groups of shots from a barrel of a small caliber weapon 5.56 × 45 mm PAR Mk.III mounted in a shooting stool ST ZA 12. Each group consisted of 20 shots divided into 2 series A and B 10 shots each.

The weapon was aimed at the axis of the guide part on the gates of the ballistic analyzer B.M.I. BA 04S located at a distance of 100 m. At the muzzle of the weapons barrel was placed a 3-axis accelerometer connected with the data cable to the Brüel & Kjær PULSE 3560 vibrodiagnostic device. The body of the accelerometer was oriented so that the x-axis belonged to the vertical plane, the y-axis to the horizontal plane and the z-axis was identical to the axis of the small-caliber barrel of the weapon.

For each shot in each series of 10 shots, the coordinate of the position of the point of impact x, y and the value of the velocity at the point of measuring gates \( v_{100} \) were assigned. At the same time, each shot was assigned data from the accelerometer and the Brüel & Kjær PULSE 3560 vibrodiagnostic device. The measured data were related to the oscillation of the muzzle of the small-caliber barrel during the shot. The oscillation data of the small-caliber barrel were in the form of acceleration of a muzzle part over time.

3. Evaluation of Measurement Data

For evaluation and interpretation of results collected during the measurement the Fourier transformation (FT) respectively Fast Fourier transformation (FFT) and then Power Spectral Density was used. Without their application, it would not be possible to get acquainted with the specifics of barrel vibration during the shot, and to be able to interpret the measured data. The Fourier transformation was used to achieve the goal to analyze the dependence of barrel oscillation on the weight of the powder charge. The method is suitable for signal processing and their transformation from time to frequency field. In general form, the Fourier transformation can be written as:

\[
F[x(t)] = x(\omega),
\]

where \( F \) is the Fourier transformation operator; \( x(t) \) is the input signal; \( x(\omega) \) is the spectrum of the input signal.

When using software resources in the computational platform, a discrete Fourier transformation is used. The
input signal does not take the form of a continuous function, but of its discrete patterns obtained at defined time points.

The discrete Fourier transformation has the form (2):

\[ x(k) = \sum_{n=0}^{N-1} e^{-j\frac{2\pi kn}{N}} x(n), \]  

where \( x(k) \) is the function of the discrete Fourier transformation; \( x(n) \) is the input signal; \( N \) is the number of measurements.

The calculation of the spectrum on the basis of definitional relations is relatively lengthy. The calculation algorithm is modified in the form of the so-called Fast Fourier Transformation (FFT). This modification is currently the most widely used form of Fourier transformation. It is used by MATLAB software.

Power spectral density (PSD) represents the energy distribution of the input signal between the individual frequency components. If \( x(\omega) \) is the Fourier transformation of the signal \( x(t) \), then the power spectral density (PSD) is defined as (3):

\[ P = \int_{-\infty}^{\infty} |x(\omega)|^2 d\omega, \]  

where \( P \) is the power spectral density; \( x(\omega) \) is the spectrum of the input signal.

For the frequency range 0 to \( \omega \) Hz, we can adjust the definition relation for the PSD calculation in the form of relation (4):

\[ P = \int_{0}^{\infty} |x(\omega)|^2 d\omega. \]  

The value of the integral \( P \) is represented by the area under the curve \( |x(\omega)|^2 \).

The area of the measured deflections of the barrel muzzle was wide (Fig. 1, left). The range of oscillations of the muzzle had to be narrowed to a width corresponding to the time of the projectile motion in the barrel (Fig. 1, right). The additional oscillation of the muzzle after the projectile crossing due to the outflow of powder gases was not significant for us. The duration of the oscillation of the muzzle during the crossing of the projectile was determined by inner ballistics calculation. The oscillation time of the muzzle ranged from 0s to 0.0007s ÷ 0.0008s, depending on the weight of the powder charge. Oscillations in this time period affect the shot just as it leaves the barrel at the muzzle. This will affect its trajectory.

The time sequence \( x(t) \) is the acceleration of the oscillations of the muzzle barrel in the x-axis, during the barrel crossing of the projectile in the time range 0 to 1ms.

For the average oscillation from \( N \) shots, in the x-axis will apply the relation (5):

\[ \bar{x}_x(t) = \frac{\sum_{i=0}^{N} |x_i(t)|}{N}. \]  

Analogously, for average oscillations in the y and z axes, the relation applies (6), (7):

Fig. 1 Identification of the barrel muzzle vibration at the time of projectile crossing
\[ \bar{x}_i(t_i) = \frac{\sum_{i=1}^{N} x(t_i)}{N} ; \]
\[ \bar{y}_i(t_i) = \frac{\sum_{i=1}^{N} y(t_i)}{N} ; \]
\[ \bar{z}_i(t_i) = \frac{\sum_{i=1}^{N} z(t_i)}{N} , \]

where \( \bar{x}_i(t_i), \bar{y}_i(t_i), \bar{z}_i(t_i) \) are the average oscillations in the x, y, z axes; \( x, y, z \) is the magnitude of the oscillation in the x, y, z axis; \( N \) number of measurements;

The time sequences of the average accelerations in the respective axes \( \bar{x}_i(t_i), \bar{y}_i(t_i), \bar{z}_i(t_i) \), are obtained from a given number of 10 shots fired.

![Oscillation course](image)

**Fig. 2 Oscillation course, course and magnitude of power spectral density in the x, y, z axis for a powder charge weight of 1.6 g**

<table>
<thead>
<tr>
<th>Power mass weight ( m_p ) [g]</th>
<th>( P_x.10^7 )</th>
<th>( P_y.10^8 )</th>
<th>( P_z.10^8 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>3.0944</td>
<td>1.0848</td>
<td>1.0413</td>
</tr>
<tr>
<td>1.55</td>
<td>6.6884</td>
<td>2.3678</td>
<td>0.9916</td>
</tr>
<tr>
<td>1.6</td>
<td>4.8020</td>
<td>1.7805</td>
<td>0.9059</td>
</tr>
<tr>
<td>1.65</td>
<td>7.7540</td>
<td>2.3794</td>
<td>2.1518</td>
</tr>
</tbody>
</table>

After defining the size of the powder charge weight in the values of 1.5 g, 1.55 g, 1.6 g, 1.65 g, we perform a defined number of shots. Then, for each mass of the powder charge, we can calculate the "average oscillations" in the individual x, y, z axes.

In the experimental part, 10 shots were made in each series A and B for each powder charge weight. The average oscillations were subsequently subjected to Fourier transformation (FT) by using MATLAB software to obtain their spectrum. The spectrum was then used to calculate the power spectral density \( P \) (Fig. 2). The values of the calculated power spectral density \( P \) for the individual powder charges in the x, y, z axes were summarized and entered in the table (Table 1). The course of the change of the spectral density energy values for the individual axes is shown in the graphs in the figure (Fig. 3).

The values of the power spectral density \( P \) from the table (Table 1) can be converted into the following graphical form, representing the functional dependence (8):
The above results show an increasing dependence of the oscillation of the barrel muzzle on the size of the powder charge. The power spectral density was chosen as the oscillation rate, the value of which increases with increasing value of the charge with a local minimum at a powder charge weight of 1.6 g. The influence of the weight of the powder charge on the scattering at a distance of 100 m is summarized in the table (Table 2), followed by a graphical representation of this dependence (Fig. 4).

### Table 2

<table>
<thead>
<tr>
<th>Powder mass weight $m_u$ [g]</th>
<th>$R_{\text{disp}}$ [mm] A series</th>
<th>$R_m$ [mm] A series</th>
<th>$R_{50}$ [mm] A series</th>
<th>$R_{100}$ [mm] A series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>62.6</td>
<td>33.5</td>
<td>25.2</td>
<td>82.2</td>
</tr>
<tr>
<td>1.55</td>
<td>59.4</td>
<td>33.1</td>
<td>29.8</td>
<td>61.7</td>
</tr>
<tr>
<td>1.6</td>
<td>55.1</td>
<td>37.3</td>
<td>39.0</td>
<td>64.9</td>
</tr>
<tr>
<td>1.65</td>
<td><strong>39.9</strong></td>
<td><strong>30.6</strong></td>
<td><strong>33.3</strong></td>
<td><strong>44.8</strong></td>
</tr>
</tbody>
</table>

As the weight value of the powder charge increases, the scattering value decreases with a local maximum at a weight of 1.6 g. At this point, the power spectral density $P$ is, but paradoxically the lowest (Table 1) and it could be assumed that this is where the accuracy of firing will be the best (Table 2), (Fig. 4).
The paradox is that the maximum value of the power spectral density in the $x$, $y$, $z$ axis (Table 1) belongs to the maximum weight of the powder charge of 1.65 g with the smallest scatter (Fig. 4), (Fig. 5, right). The local minimum of the values of the power spectral density in the $x$, $y$, $z$ axis with a slightly higher scattering belonged to the mass of the powder charge $m_0 = 1.6$ g. It could be expected that the minimum value of the power spectral density in the $x$, $y$ axes would correspond to a small scattering value. This is not the case.

4. Conclusions

The behavior of the barrel muzzle during the time of projectile crossing in the barrel, as well as the size of the muzzle deflection also affects by other parameters. Among the parameters influencing the oscillation of the muzzle, we can include the shape of the outer barrel jacket, the thickness of the barrel wall and the length of the barrel mounting in the weapon casing.

It is difficult to determine the level of mutual interaction of the mentioned parameters. Mainly due to the fast-moving event of the shot, where there are small but regular changes in entry conditions. Each action is then unique with slightly altered dynamics of its course. This is reflected in the different course of vibration of the barrel muzzle [2, 3, 6, 7].

References:

Research of Air Pollution Possibilities of Panamax Containerships Sailing to Klaipeda Container Terminal in the Port of Klaipeda

A. Dementjev

Klaipeda University, Herkaus Manto 84, 92294, Klaipėda, Lithuania, E-mail: aleksandr.dementjev@hotmail.com

Abstract

This work aims to determine the air pollution from diesel oil and LNG powered Panamax type vessel, which are going to Klaipeda seaport, to “Klaipeda Container Terminal”. This work is based on the result from the navigational simulator. With the use of a simulator, there is an estimated amount of containerships emissions that reach the city of Klaipeda.

KEY WORDS: emissions, containership, a port of Klaipeda, air pollution

1. Introduction

Global maritime transport sector supported in the world economy is developing successfully. There was an acceleration in the global maritime trade growth rate, which reached 4%. Being the highest rate in the last five years, it led to raised economic sentiments in the shipping industry. The total volume of transported goods increased by 411 million tons and reached 10.7 billion tons, with almost half of the increase recorded in the transportation of dry bulk cargo. Global containerised trade increased by 6.4%, following unprecedented low growth over the previous two years. The volume of dry bulk cargo transportation increased by 4.0% compared to 1.7% in 2019, while the growth rate of crude oil transportation slowed down to 2.4%. The reduction in deliveries from the states that are members of the Organization of Petroleum Exporting Countries was offset by an increase in eastbound transportation from the Atlantic basin to Asian countries. This new trend has changed the structure of crude oil transportation as a result of a decline in the share of traditional oil suppliers from West Asia. Due to the expansion of world oil refining capacities, particularly in Asia, and the attractiveness of gas as an environmentally friendly energy source, the volume of transportation of oil products and gas increased by a total of 3.9% in 2019. The vessels’ power plants enable the vessel movement, the operation of individual units, and the vital activities of the crew and passengers. The functioning of such plants affects the environment and has its specific features. It is not a coincidence that protecting the environment and the climate from maritime transport emissions plays an increasingly important role as the growing maritime traffic is accompanied by an increase in environmental pollution and a negative impact on the climate and ecology [1].

Emission is the entry of gaseous, liquid and solid pollutants or energy (heat, sound, radiation) emitted from the companies, houses, vessels and cars into the environment [4-8]. As the shipping industry is becoming more intensive, this causes many challenges. Some of them are related to the environment: both shipbuilding and maritime transport have a negative impact on water, coasts, wildlife and the atmosphere. The main reason causing the said negative impact is emissions and waste from vessels able to spread within a radius of several hundred kilometres and even reach the land. Air pollution from vessels is caused by the working process of vessel engines. The most important pollutants emitted by diesel engines are the result of the fuel combustion process. While the type of fuel used plays a major role in the composition of the emissions, the engine speed is an important factor determining the amount of NOx emitted. The main pollutants are chemical and physical. Such pollutants can have local, regional and global prevalence.

As we can see, the greatest impact is associated with air pollution. MARPOL 73/78 is the main convention setting limits on the pollution from vessels. The increased intensity of shipping leads to making stricter requirements for vessels. Let’s take the Baltic Sea as an example and analyse it. The area of this sea basin is only 0.12% of the world’s total ocean area. However, the shipping intensity is huge there: it serves more than 60 thousand vessels every year with total fuel consumption of 5.6 million tons (more than 1.6% of global fuel consumption) [3].

2. Situation Analysis

Maritime container shipping is of key significance to the global trade in intermediate and industrial consumer goods. It represents regular linear transportation forming a network of transport links, including direct lines and lines with container transhipment in large transhipments ports.

Modern container ports have berths equipped with specialised container cranes, therefore, the majority of new container vessels do not have lifting devices installed. In 2017, only 4.2% of the container vessels launched (according to deadweight) were equipped with their own lifting devices and were intended for markets where the terminals are not equipped with the necessary container handling cranes, including some small island developing states as well as small and remote ports, where the volume of cargo flows does not justify the investment in port cranes.

On the one hand, maritime traffic can be considered as a relatively clean mode of transport. Typical CO2 efficiency of a vessel ranges from 0 to 60 grams per tonne-kilometre, while this range is from 20 to 120 for rail transport and from 80...
to 180 for road transport (IMO 2009). The types of vessels vary widely, and CO₂ efficiency generally increases with the size of the vessel. For instance, CO₂ emissions per tonne-km (grams per year) for container vessels (with a capacity not exceeding 500 TEU) would be 31.6, i.e., three times higher than those emitted from Panamax container vessels with a capacity of more than 4,400 TEU (Psaraftis and Kontovas, 2008). This difference is even greater for bulkers, where the difference between smaller vessels (up to 5000 dwt) and (> 120,000 dwt) is more than 10.

The ports with the highest emissions from the vessels are Singapore, Hong Kong (China), Tianjin (China) and Port Klang (Malaysia). In all emission categories, the port of Singapore has the highest emission levels, while other ports have different positions depending on the different categories of emitted pollutants. The 4 best port classifications for CO₂ emissions are similar to classification for NOₓ and SOₓ, and PM ratings are similar. All information is available in the below Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Top 4 ports (CO₂ emissions)</th>
<th>Share of total</th>
<th>Top 4 ports (SOₓ emissions)</th>
<th>Share of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>5.9 %</td>
<td>Singapore</td>
<td>6.5%</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2.2 %</td>
<td>Hong Kong</td>
<td>2.3%</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>2.0 %</td>
<td>Rotterdam</td>
<td>2.2%</td>
</tr>
<tr>
<td>Port Klang</td>
<td>1.9 %</td>
<td>Port Klang</td>
<td>2.1%</td>
</tr>
</tbody>
</table>

The list of ports with the highest emissions is not very surprising: most of these ports are among the largest ports in the world with the most intense shipping activity. The difference between the classification according to CO₂ and SOₓ emissions can be explained by policy, particularly the EU Directive on low sulphur content fuels. All information are available in Table 2 [1].

### Table 2

<table>
<thead>
<tr>
<th>Ports with lowest CO₂ emissions per ship call</th>
<th>Country</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitakyushu</td>
<td>Japan</td>
<td>Kyllini</td>
</tr>
<tr>
<td>Imabari</td>
<td>Japan</td>
<td>Guernsey</td>
</tr>
<tr>
<td>Kyllini</td>
<td>Greece</td>
<td>Sundsvall</td>
</tr>
</tbody>
</table>

The ports with the lowest relative pollution rates are the ports of such countries as Japan, Greece, the UK, the USA and Sweden. The port with the lowest relative CO₂ emissions is Kitakyushu (Japan); the lowest SOₓ emissions are in the port of Kyllini (Greece). Like the absolute classification, the CO₂ and NOₓ classification is similar to that for PM and SOₓ. The ranking is dominated by ports specialising in Ro-Ro type maritime transport. The emission levels of Ro-Ro vessels are relatively low compared to other types of vessels. The difference between the classification for CO₂ and SOₓ emissions can be explained by the EU Directive on the use of low sulphur content fuels at berths.

In the analysis of ship pollution in the article, we will use the results obtained in the simulator, i.e. we will analyze the arrival of the Panamax type ship to the KCT terminal and the departure from the port during the year. The dimensions of the container vessel are given in Table 3 and the route is shown in Fig. 1., the ship sailed took 56 minutes (0.93 h) [2].

### Table 3

<table>
<thead>
<tr>
<th>The dimensions of the container vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Panamax” containership</td>
</tr>
<tr>
<td>Length: 320 m</td>
</tr>
<tr>
<td>Width: 34 m</td>
</tr>
<tr>
<td>Draught: 12.5 m</td>
</tr>
<tr>
<td>TEU capacity: 6000</td>
</tr>
</tbody>
</table>

All information about changes in fuel consumption, engine power and speed during the sailing time is provided by the simulator. The results are reported in Fig. 2.
3. The Methodology of the Study of Air Pollution of Panamax Containership

The vessel’s pollution calculations will also require the use of terminal capacity per year. Reconstruction of the quays of the terminal and dredging of the water area is currently underway, and upon completion of this project, the terminal will be able to accept Panamax vessels. Therefore, it should be mentioned that the terminal does not accept Panamax vessels yet, but during the simulator experiment it was assumed that the terminal can accept Panamax container vessels.

Based on the information obtained from various sources, we can state that the capacity of Klaipeda Container Terminal (KCT) (Lith. KKT) in TEU was 461,396 TEU in 2019. This means that the number of vessels arriving at the KCT terminal is calculated according to the following formula:

\[ T = \frac{p_{\text{kkt}}}{D_t}, \]

where \( T \) – quantity of the vessels, pcs.; \( p_{\text{kkt}} \) – “KKT” terminal throughput per year, TEU; \( D_t \) – ship capacity, TEU.

Using data from the tables, we will calculate the ship's emissions according to the following formulas:

\[ \text{CO} = N \cdot \Delta \text{CO} \cdot t / 60 \]

where \( N \) – engine power, kw; \( \Delta \text{CO} \) - CO emission coefficient, g/kwh.

\[ \text{CO}_2 = \sum q \cdot \Delta \text{CO}_2 \]

where \( \sum q \) – ship fuel consumption; \( \Delta \text{CO}_2 \) - CO \(_2\) emission coefficient, g/kWh

\[ \text{SO}_x = \sum q \cdot \Delta \text{SO}_x \]

where \( \Delta \text{SO}_x \) - emission coefficient, g/kwh;

\[ \text{NO}_x = N \cdot \Delta \text{NO}_x \cdot t \]

where \( \Delta \text{NO}_x \) - emission coefficient, g/kwh; \( t \) – time, h.

\[ \text{PM} = N \cdot \Delta \text{PM} \cdot t \]

where \( \Delta \text{PM} \) - PM emission coefficient, g/kwh;

\( \Delta \text{CO}_2, \Delta \text{SO}_x, \Delta \text{NO}_x, \Delta \text{CO} \) and PM emission coefficients are available in Tables 4 and 5.

<table>
<thead>
<tr>
<th>Emission</th>
<th>Marine diesel oil</th>
<th>Liquefied natural gas (LNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2)</td>
<td>3,2</td>
<td>2,1</td>
</tr>
<tr>
<td>SO(_x)</td>
<td>0,001</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4

Emission factors for \( \text{CO}_2 \) and \( \text{SO}_x \) for different fuels
Emission factors for NO\textsubscript{x}, CO and PM for different fuels

<table>
<thead>
<tr>
<th>Emission</th>
<th>Marine diesel oil</th>
<th>Liquefied natural gas (LNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\textsubscript{x}</td>
<td>10 g/kWh</td>
<td>4 g/kWh</td>
</tr>
<tr>
<td>CO</td>
<td>5 g/kWh</td>
<td>3 g/kWh</td>
</tr>
<tr>
<td>PM</td>
<td>0.5 g/kWh</td>
<td>0.1 g/kWh</td>
</tr>
</tbody>
</table>

4. Research and Calculation of Air Pollution of Panamax Containership

During the simulated passage, it was obtained that the Panamax vessel consumed 1312.8 kg of fuel. During 56 minutes of voyage, the average engine power was 6400 kW. Taking the fact that the „KCT“ handles an average of 77 Panamax containerships. All calculations using formulas (1), (2), (3), (4), (5) are made when each vessel made 2 voyages.

Table 6

The annual results of pollutant emissions of LNG and marine diesel powered Panamax container vessel that arrives to and departs from KCT

<table>
<thead>
<tr>
<th>Emission</th>
<th>Marine diesel oil</th>
<th>Liquefied natural gas (LNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO\textsubscript{2}</td>
<td>470507.52 kg</td>
<td>308770.56 kg</td>
</tr>
<tr>
<td>SO\textsubscript{x}</td>
<td>147 kg</td>
<td>0 kg</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>9116.80 kg</td>
<td>3666.43 kg</td>
</tr>
<tr>
<td>CO</td>
<td>4583.04 kg</td>
<td>2749.82 kg</td>
</tr>
<tr>
<td>PM</td>
<td>458.3 kg</td>
<td>91.66 kg</td>
</tr>
</tbody>
</table>

To estimate the amount of emissions that reach city of Klaipeda (70 percent of the time wind direction is toward the city).

Table 7

The annual results of air pollutant emissions that reach the city of Klaipeda

<table>
<thead>
<tr>
<th>Emission</th>
<th>Marine diesel oil</th>
<th>Liquefied natural gas (LNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO\textsubscript{2}</td>
<td>329155.26 kg</td>
<td>216139.39 kg</td>
</tr>
<tr>
<td>SO\textsubscript{x}</td>
<td>102.9 kg</td>
<td>0 kg</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>6381.76 kg</td>
<td>2566.5 kg</td>
</tr>
<tr>
<td>CO</td>
<td>3208.13 kg</td>
<td>1924.87 kg</td>
</tr>
<tr>
<td>PM</td>
<td>320.81 kg</td>
<td>64.16 kg</td>
</tr>
</tbody>
</table>

After the calculations, Table 7 are reported emissions which reach the city of Klaipeda. The most of emissions is CO\textsubscript{2} and NO\textsubscript{x}. The smallest amount of emissions is SO\textsubscript{x} and PM.

5. Conclusions

Air pollution and specifically vessel’s air pollution remain worrying concerns. Indeed, exposure to air pollutants can lead to an increase not only in morbidity but also in mortality. Of course, vessels are not the only cause of air pollution.

Port equipment, land vehicles used in port’s work also emits significant emissions. For the year to KCT arrive 77 Panamax type vessels. After calculations, it was revealed that for the most part emissions from ships are CO\textsubscript{2} and NO\textsubscript{x}.

References:

Development of Modal Split in the Czech Republic According to National Census

T. Horník¹, J. Froněk², D. Vymětal³, J. Chlumecký⁴

¹University of Pardubice, Faculty of Transport Engineering, Department of Transport Technology and Control, Studentska 95, 532 10 Pardubice, Czech republic, E-mail: tomas.hornik@student.upce.cz
²University of Pardubice, Faculty of Transport Engineering, Department of Transport Technology and Control, Studentska 95, 532 10 Pardubice, Czech republic, E-mail: jan.fronek@student.upce.cz
³University of Pardubice, Faculty of Transport Engineering, Department of Transport Technology and Control, Studentska 95, 532 10 Pardubice, Czech republic, E-mail: daniel.vymetal@student.upce.cz
⁴University of Pardubice, Faculty of Transport Engineering, Department of Transport Technology and Control, Studentska 95, 532 10 Pardubice, Czech republic, E-mail: jaroslav.chlumecky@student.upce.cz

Abstract

One of the key parameters during the analysis of traffic in the cities is the modal split, which shows how is the role of different modes of transport in the city. Every 10 years in the Czech Republic, the Czech Statistical Office makes a census of houses, people and flats and a regular commute to work and school (or modal split). However, this data is not using for the further needs of city traffic planning, while small towns (15-60,000 inhabitants) have not another source of data for planning of traffic behaviour. This paper follows the final report from the CYCLE21 project, which analysed data from 2001. This paper examines the development of data between 2001 and 2011 (when the last census took place in the Czech Republic) and analyses the trend of change of traffic behaviour. Concurrently, this paper introduces methodological documents created by the authors of the paper for the future census in 2021 so that it is possible to make prediction of modal split in individual cities in the Czech Republic.

KEY WORDS: the prognosis of data, modal split, Czech Statistical Office, commute, SUMP

1. Introduction

The United Nations points to two fundamental trends. The first is the growing population on Earth, which currently stands at over 7 billion people and, according to medium estimates, will reach 10 billion people by 2050 [24]. The second of these trends is the increasing urban population and depopulating countryside. Cities are a magnet and at the same time a sustainable structure and must provide the place where the world's population will live, as according to the European Commission (2012) more and more people are moving to cities – 74% of the European population live in them and is estimated to grow by 2050 at 82%. By comparison, in 1950, only 30% of the world's population lived in cities; in 2005, 40% of the world's population was already in cities (United Nations, 2005).

Empirical research [6] has concluded that the key parameters of a sustainable city are that it should have more than 25,000 inhabitants (preferably over 50,000), with a medium population density of over 40 people per hectare. It should be a city with the support of mixed land use, which would allow the proximity of everyday travel destinations (a city of short distances).

Studies on the principles of sustainable transport systems [2, 4] have already identified four key principles in the first decade of the 21st century, but they have not yet been able to implement urban planning. These are the following principles.

1. Reducing the need for travel - substitution - there will be a reduction of some trips and reasons for market change (e.g. online shopping).
2. Transport policy measures - change in the distribution of the modal split.
3. Spatial planning measures - shortening distances (urban decentralization).
4. Technological innovations - increasing the efficiency of the transport system.

It is therefore clear from the above that more and more people will live in cities, which will result in an increasing demand for transport to work, school facilities, medical facilities, etc., not only within cities but within the whole network. These predictions are further supported by the fact that the number of category B driving licenses (passenger car up to 3.5 t) in the population continues to grow, as evidenced by Fig. 1, which presents the cumulative development of driving licenses in the United States, Germany and the Czech Republic [11, 12, 20, 25, 27].

The development of driving licenses itself is not so authoritative, but it can also be supported by the development of the cumulative number of passenger cars up to 3.5 t in relation to the number of inhabitants. Fig. 2 shows the number of vehicles per person in a given country [10; 23].

From the above, it is clear that the situation on the roads will deteriorate and the currently set system is unsustainable and it will be necessary to approach a comprehensive system solution at the level of cities with less than 100 thousand inhabitants.
2. Traffic Behaviour

The key challenges faced by urban planners in the past are underestimated in traffic behaviour [1, 3, 5, 9, 26]. Nevertheless, it is remarkable that transport planning "survived" all these crises, which appeared almost intact, perhaps with minor changes. Two basic principles are still enshrined in the transport planning approach used.

- Travel is a derived demand, not an activity that people want to do for themselves. Travel only leads to the value of the activity that is at the destination (therefore transport is just a tool of implementation).
- People minimize their travel costs, especially because of the combination of travel costs and travel time. These two basic principles have important implications because they are embedded in most analyzes and evaluation studies. They help explain the predominance of transport solutions in urban problems and the huge increase in faster and longer distance travel, as increased cruising speed outweighs increased travel costs.

Although travel times may have remained constant as cities spread, distances and speeds increased significantly [4, 7, 8, 17]. Local public transport, cycling and walking have become less attractive, which in turn has led to greater use of the car. Car dependency and increased decentralization of cities are difficult processes that are not easy to reverse.

Travel time is important for commuting, but as travel patterns change and leisure travel increases, travel time may become a more positively valued activity [18, 21, 22]. Escape theory [13] assumes that mobility at leisure is an attempt to compensate for the declining quality of life in cities. Travel opportunities are required to escape away from the everyday environment of something completely different. Much of the free time is devoted to the need for travel, and travel activity is valued.

There is a need to change traffic behaviour so that more people use means of transport other than cars. However, this has not been successful in the Czech Republic for a long time. As early as 1999, Dekoster and Schollaert noted that almost 50% of car journeys in the city are shorter than 8 km and 30% of journeys are shorter than 3 km. If we look at the data from Prague, this still does not change, according to a survey of traffic behaviour [19], in Prague, 21% of journeys shorter than 2 km are made by car.

3. Open Data for Traffic Planning

The Czech Republic has two types of data that are collected at regular intervals and are publicly available for traffic analysis. Every 5 years, the Road and Motorway Directorate of the Czech Republic (RSD) performs a census of traffic intensities on motorways, roads and selected local roads. The data can be used for basic evaluation of traffic intensities in cities. It is also possible to perform analyzes of the composition of traffic flows, determination of peak hours or load of the entire traffic network. The RSD only counts vehicles that pass through a given road profile [14]. It is not possible to further determine the modal split from these data, which is a basic indicator of the quality of traffic in cities (nor the direction of traffic flows - OD matrix). Modal split can be determined as a nationwide Population Censuses, which is collected by the Czech Statistical Office.

The Population Censuses in 2011 was a nationwide census in the Czech Republic. It took place at midnight from Friday 25 to Saturday 26 March 2011. Regulation No. 763/2008 of the European Parliament and of the Council of the European Union provided that the census was to take place in all European Union (EU) member states every ten years, starting in 2011, with further reference years to be determined by the European Commission as the executive body of EU.

The data that is suitable for use in traffic analysis are as follows:

- Total regular commuting;
- Commuting to work;
- Commuting to schools.

Based on these data, it is possible to determine in detail the modal split, which tells about the behaviour of residents in the city. The project CYCLE21 – Analysis of the needs for building cycling infrastructure in the Czech
Republic, which was implemented within the National Research Program 2004–2009 of the Ministry of Transport of the Czech Republic [6], dealt with this determination. The authors of the project identified a modal split, which served as a basis for the analysis of urban traffic (Fig. 3). The project was beneficial especially for cities with 10 to 60 thousand inhabitants, for which it can be too financially demanding to have an extensive transport analysis, including the modal split.

The authors of the CYCLE21 project evaluated the data of the Population Censuses in 2001, but they did not continue in 2011. It was not possible to compare how the modal split of individual cities changed. At the same time, there was enormous interest in these data in the Czech Republic. In 2017, Dr. Jirsa also drew on the CYCLE21 project during the elaboration of the Nymburk City Communication Network Concept [16], where he presented this data as one of the key inputs.

The authors of the article therefore follow the work of the authors of the CYCLE21 project so that it is possible to further evaluate the data according to the same methodology. This continuous evaluation is more than desirable, because in the Czech Republic at present (2020) there are no more comprehensive data for the whole country. It should also be mentioned that the study of the Prague Institute of Planning and Development (IPR) tried to follow the CYCLE21 project [15]. However, this study only worked for the capital city of Prague. The authors of both projects [6, 15] did not publish a methodological procedure in their projects, so that it was possible to follow up on the projects.

4. Methodical Data Separation

As part of the Population Censuses in the Czech Republic in 2001, commuting to all cities in the Czech Republic was determined. It was further divided into gender, total commuting time, modal split and what type of employment commuting is made up of. These data were then created for individual districts. The problem arises with the Population Censuses from 2011, the modal split for individual cities is missing. Although there are data for individual districts, they are unusable or only to a limited extent applicable to the cities themselves. The task is therefore to separate the individual values of detours within the districts for the cities themselves, which could further use them for urban infrastructure planning.

For the separation of data, the values from the Population Censuses from 2001 will be used for the individual division of transport work both within districts and individual cities, as well as the values from the 2011 census of population, houses and dwellings for districts and population in 2001 and 2011, and the following relation no.1.

$$ m_A^{2011} = \frac{p_A^{2001}}{p^{2001}} \cdot \frac{m_A^{2001}}{o_X^{2001}} $$

where $m_A^{2011}$ is a commute to the city $A$ in 2011 within a specific transport segment, $p_A^{2001}$ is the population of city $A$ in 2001, $p^{2001}$ is the population of city $A$ in 2001, $m_A^{2001}$ is a commute to the city $A$ in 2001 within a specific transport segment, $o_X^{2001}$ is commuting to district $X$ in 2011, $o_X^{2001}$ is commuting to district $X$ in 2001.

5. Interpretation of Results

Within the comparison of cities with 15 - 60,000 inhabitants, 102 cities were compared. The following Figs. 4 and 5 interpret the partial results.

The total regular commuting based on data from the Population Censuses has a declining trend between 2001 and 2011 (except for the municipality of Brandýs nad Labem). This difference is mainly due to the geographical location of cities, or the proximity of larger, more dominant centers (cities around 100,000 inhabitants). The results of total commuting and its comparison are, of course, also dependent on the change in the number of inhabitants during the observed period. The population of Brandýs nad Labem increased by 2,200. It could be said here that this is a direct relationship between the growth of the population and the growth of total commuting.

If we deal with the total commuting in whole districts, the trend is, as with cities, declining between 2001 and 2011. Although the number of inhabitants in the number of monitored districts increased significantly, the total value of commuting to the given district decreased in all cases. For example, in the district of Prague-East, the population increased by more than 60,000, and yet commuting to this district decreased by more than 1,000 inhabitants. Here,
however, the result of the research is understandable due to the geographical location, which is close to the center of Prague. Directly proportional to the decrease in the number of inhabitants and at the same time commuting is, for example, the Karviná district, where the number of inhabitants decreased by more than 20,000 between the monitored years, as well as the size of commuting. The population also increased in the Benešov, Kladno, Beroun, Mladá Boleslav and Nymburk districts. However, this did not change commuting, the reason for the increase in population is mainly more economically affordable housing near the metropolis, which is the dominant destination for commuting to work and school.

![Fig.4 Comparison of commuting between 2001 and 2011 (selected cities)](image)

**Modal split** data was divided commuting in cities by public bus transport, train, private motor vehicle, public transport, cycling and pedestrian mode of transport.

**Public bus transport**
In almost all monitored cities, regular bus transport commuting decreased by 50-75%, in Tachov, Dvůr Králové nad Labem, Bílina and Teplice the value of the decrease was above 80%. The only town where the decline in commuting by regular bus was only 10% is Brandýs nad Labem. However, this figure is due to the fact that it is the only city where total commuting has increased between these years.

**Train**
Like regular bus transport, this type of means of transport has a declining trend in the number of people, in all monitored cities. In some cities, this information could not be ascertained mainly because the city does not have a train connection.

**Private motor vehicle (PMV)**
Compared to other modes of transport, commuting by private motor vehicle has a growing trend. The growing trend ranges from 0% to 62%. There is an extreme increase in PMV commuting in the already mentioned town of Brandýs nad Labem / Stará Boleslav, where the increase in commuting is 233%. The town of Kopřivnice, Zábřeh, Šternberk or Frenštát pod Radhoštěm also has a higher increase than the value of 50% within commuting with PMV. Commuting via OMV has a slightly declining trend in 35 out of 102 cities, but only in percentage units.

**Public transport**
From the point of view of commuting by public transport, the trend is again rather declining, the only town where there has been a growth is again the town of Brandýs nad Labem/Stará Boleslav. The difference between commuting by public transport in 2001 and 2011 remained virtually unchanged in Poděbrady or Nymburk. This figure was not available for many cities.

**Cycling**
The decline in commuting by bicycle to work or school is, as well as commuting by public line bus, worth 50-75%. As with other modes of transport, the value of the decline is in principle directly proportional to the trend in the development of total commuting to selected cities.

**Walking**
The last type of transport within the solved modal split of commuting is the pedestrian transfer of people to jobs and schools. There was a decrease in about 65% of selected cities, while in about 30% (31 cities out of 102) there was an increase in the number of people reaching the destination on foot. Cities with a higher increase in attendance above 50% include, for example, Třinec, Uherské Hradiště, Brandýs nad Labem/Stará Boleslav, Frýdek-Místek and Uherský Brod.

In summary, for all modes of transport, it can be said that commuting by most of the selected means of transport within the modal split depends on the trend of the development of total commuting in the monitored period. Commuting by public transport buses, public transport, trains and bicycles there was essentially a clear decrease in all monitored
cities. For the selected type of transport by PMV or pedestrian transfer, there was a growth in selected cities. This can be influenced by several factors, such as higher economic availability of buying and operating your own car, or insufficient provision of the city by public transport and the related impossibility of choosing another more efficient form of transport to jobs and schools than PMV.

The issue of the average time spent in public transport depends on the value of total commuting and its trend within the observed period. Due to the fact that the value of total commuting has a declining trend in the observed period, the partial values of the number of commuters according to the time spent commuting are derived from this. These numbers of people logically also have a declining trend due to the total commute. The numbers of commuters were monitored according to the time spent in the vehicle according to the following minute intervals: up to 14 minutes, 15-29 minutes, 30-44 minutes, 45-59 minutes and more than 60 minutes.

The growth occurred only in the town of Brandýs nad Labem, in all time intervals. Another interesting feature is the increase in the number of commuters over 60 minutes to the cities of Svitavy and Jihlava. When it comes to the development of the average time spent in a vehicle commuting to work and schools, this value is lower in most cities in 2011 compared to 2001. The increase in the average time spent in a vehicle commuting is only in 6 cities where increase value only in percent units. The largest decrease in the value of the average time spent on commuting occurred in the towns of Chomutov and Teplice, where the decrease is about 16%. These values are usually given by the general trend of accelerating public transport due to more efficient and more modern means of transport due to general technical progress.

![Average travel time spent commuting (selected cities)](image)

**Fig. 5 Average travel time spent commuting (selected cities)**

### 6. Conclusions

The aim of the work was to follow up on the CYCLE 21 project [6] and to compare the development of basic urban indicators with a number of 15,000-60,000 inhabitants. The basic input was publicly available data from the Czech Statistical Office, the years 2001 and 2011 (following the future census in 2021). In the vast majority of cases, commuting has decreased in smaller cities. In some cities, the value of total commuting has dropped by up to half. The declining number of jobs is a major problem for these smaller cities. This is also influenced by the upward trend of people with higher education, which are no longer used in these cities. The data interpret the current trend in the Czech Republic - depopulation of the countryside and migration of inhabitants to large cities, or within driving distance. As predicted by the European Commission.

As part of the modal split, we are seeing a significant decline in the number of people commuting to cities using public transport, which is due to the fact that as these cities cease to be attractive for commuting, so does the number of public transport connections on offer. The trend in public transport is integrated transport systems, whose majority destinations end in metropolises or regional cities and "avoid" smaller cities, which are addressed in this work. Many of these trends have been warned at the beginning of the millennium by the work of foreign authors [4, 7, 8, 17].

In 2021, another census will take place in the Czech Republic. These data are the only permanent source of traffic data for cities of 15,000-60,000 inhabitants, so it is necessary to ensure their publication in an acceptable format, so that this data can be further worked on. In the case of traffic data (modal split and commuting), the authors recommend focusing not on individual administrative units (districts, regions), but directly on municipalities. The authors also recommend a thorough description of the methodological procedure for evaluating the data in the census and in subsequent research reports, so that it is possible to follow up on the work in the coming years.
References

20. Ministerstvo dopravy České republiky, 2020, Řidičská oprávnění kategorie B v České republice, [e-mail communication]
Basis for Simulating the Permeable Performance of Rail Transport in Crisis Situations

E. Sventeková¹, Z. Gašparíková²

¹University of Zilina, Faculty of Security Engineering, Univerzitná 8215/1, 010 26 Zilina, Slovakia, E-mail: eva.sventekova@fbi.uniza.sk
²University of Zilina, Faculty of Security Engineering, Univerzitná 8215/1, 010 26 Zilina, Slovakia, E-mail: zuzana.gasparikova@fbi.uniza.sk

Abstract

The consequences of crisis situations on railway infrastructure often lead to a significant reduction in its throughput or disruption of traffic flows. Computer simulations play an important role in deciding whether to restore traffic and their capacities. The authors describe the technical and mathematical basis for the calculation of the permeable performance of railway transport, which were used in the creation of a simulation program for the optimal organization of railways' operational work after disruption of their operation.

KEY WORDS: rail transport, permeable performance, crisis situations

1. Introduction

When the transport performance of rail transport is disrupted, it is necessary to establish in the critical section such an organization of work that would ensure the required transport performance in compliance with the technology set by the traffic regulations. Preliminary verification of the anticipated technology in railway transport is impossible in practice. The only option is a computer simulation according to the changed transport and transportation conditions, resulting in a proposal for measures to resume the transport process.

The Railways of the Slovak Republic approached the Faculty of Security Engineering of the University of Zilina with an offer to cooperate in solving tasks in the field of railway traffic management in crisis situations. We have been dealing with these tasks for several years in the research team. The result of the joint effort is a computer program designed to simulate the running of trains in track sections on the basis of pre-entered data on traction vehicles - locomotives and a typical wagon set on real track sections of the Slovak railway network [4].

Algorithms based on mathematical calculations and the use of operational research methods form a space for analysis and possible generalization of knowledge about the behaviour of the investigated transport process. This makes it possible to draw general conclusions and prepare measures in advance that will minimize the negative effects of crisis phenomena on traffic. This program is currently an important tool for crisis managers in planning transport security in the process of resolving crisis phenomena by rail.

2. Basis for Simulating the Permeable Performance

In the research team, we formulated the following five basic starting points, which were the input for the creation of a computer program that simulates the operation of rail transport in crisis situations. When solving the technology of train transport, all relations to the calculations of line and station intervals and binding methods of train operation in line sections were respected.

2.1. Modification of the Calculation of Permeable Performance According to the Type of Safety Device

The permeable performance of a railway section indicates the number of trains that pass through the section at a certain time, usually 24 hours. Transport can be organized according to the commercial (non-parallel) train schedule, when trains move at different speeds, or the maximum (parallel, crisis) train schedule, when trains move at the same speed. A basic general relationship was used to calculate the permeable performance of \( N_d \):

\[
N_d = \frac{1440}{t_{p,obs} + t_{p,mz}}.
\]  

In this relation, \( t_{p,obs} \) is the average time of occupying a line section by one train and \( t_{p,mz} \) is the average time of the gap between two trains. This general relationship has been modified for different types of signaling devices in line sections and traffic points and according to traffic technology depending on the number of tracks.
2.2. Modification of the Equation of Motion

To solve the running time of the train in the track sections, the equation of motion of the train in the form of:

\[ F_o - o_{vh} - o_{vd} - o_t = 10^3 (m_h + m_d)(1 + \varphi) \frac{dv}{dt}, \]

where \( F_o \) is the tractive force on the circumference of the drive wheels, N; \( o_{vh} \) – vehicle resistance of the traction vehicle [N]; \( o_{vd} \) – vehicle resistance of transported vehicles, N; \( o_t \) – track resistance, N; \( m_h \) – a mass of the traction unit, t; \( m_d \) – a mass of the transported vehicles, t; \( \varphi \) – coefficient of rotating parts, N.kN\(^{-1}\) and at the same time the following applies:

\[ o_{vh} = o_{m,vh} m_h; \quad o_{vd} = o_{m,vd} m_d; \quad o_t = o_{m,t} m_h + o_{m,t} m_d, \]

where \( o_{m,vh} \) – coefficient of vehicle – resistance of the traction vehicle, N.kN\(^{-1}\); \( o_{m,vd} \) – coefficient of vehicle resistance of the rolling stock, N.kN\(^{-1}\); \( o_{m,t} \) – coefficient of the track resistance, N.kN\(^{-1}\).

The main inputs of the equation of motion are the power of the traction vehicle and the resistances acting against the movement of the train. Depending on the course of the maximum traction force, it is also possible to evaluate the course of the maximum achievable speed, when the traction force and resistances are in balance. This speed must not exceed the permitted train or line speed. By comparing them with the speed at which the train enters the section, it is possible to solve the running time as partial calculations for the movement of uniformly accelerated, slowed down, or running at a steady speed. The decisive criterion in the application of the equation of motion of the train was also the ability of traction vehicles to reach such a constant speed, which will not conflict with the so-called minimum hourly speed [6].

2.3. Use of Load Diagrams

To assess the selected traction units, some relationships from the load diagrams were applied, which are based on the above equation of motion of the train and describe the possibilities of traction units in terms of excess or lack of traction. For the selected traction vehicle, the achieved train speed was continuously tested during the calculations with the so-called technological hourly or constant speed of the traction unit [7].

2.4. Erlang's Distribution of a Random Variable

For the application of the theory of mass service, an extensive statistical investigation was performed in 20 track sections. Statistical sets of train running times along track sections were tested by different types of random variable distributions using the "chi-square" goodness-of-fit test.

The test results confirmed that the most advantageous type of distribution of a random variable, which can be used to describe the running time in track sections, is the Erlang’s distribution, which works with two parameters, the integer parameter \( a \) and the real parameter \( b \). Due to the fact that it was possible to prove that the parameter \( a \) is a constant for all track sections, the calculations are significantly simplified. For the mean value (arithmetic mean) of the statistical set \( x_p \), the parameter \( b \) is calculated from the relation [4].

\[ a = x_p b. \]  

Both parameters can be used in the distribution function of the distribution in the form

\[ f(x) = \frac{b^a x^{a-1}}{(a-b)!} e^{-bx}. \]  

2.5. Use of the Mass Service System M/M/n

When choosing the type of mass service system, we proceeded from the basic classification of mass service systems, which evaluates the input flow of requests entering the system, the number and order of service stations, the service time of the request and the behavior of requests in the queue. In our case, the requirements were trains entering the track sections, the service stations of the relevant tracks, the service time of the train running time of the track section and the queue of trains waiting to enter the track section.

By default, this system is classified as a mass service system M/M/n, which represents the Poisson input process and the exponential distribution of service time. This system also allows the broadest mathematical approach to the solution and provides the most output probabilistic characteristics of the behaviour and efficiency of the system [3].

At this point, it should be noted that the researchers, based on the application of the system and empirical
research, have concluded that the assessment of railway traffic as a public service system shows some inaccuracies and underestimates the performance of the system. This is mainly influenced by human interventions in train traffic, in particular the organized entry of trains into the first track section, which cannot be considered stochastic and at the same time by systematically influencing the train queue in case of operational failures. The statistical survey also did not confirm the exponential distribution of the operating time, but proved the Erlang’s distribution, which governs the running times of trains on track sections [8].

Fig. 1 Graphic representation of trains entering the track section [6]

Graphically, this starting point is shown in (Fig. 1). The individual variables used in the figure express the following values: $t_j$ – journey time on the track section; $W_n$ – the interval of the subsequent journey, after which the running of the next train may follow; $t_{mez}$ – the time gap for the next train to run; $t_{obs}$ – the time of occupation of the line section by the 1st train.

3. Discussion

In solving this solution, we concluded that it is questionable to assess the input stream of requests - trains entering the first track section, because we can talk about the system of collective service only if the input stream of requests is random. In the organization of railway transport, however, we cannot talk about a purely accidental entry of trains into the first track section. Trains do not appear, they do not arise by chance, but their creation is the result of organized activity in the setting stations according to a predetermined plan, the train schedule, or operatively as needed. Any disturbances are systematically eliminated by the dispatching apparatus [1].

Furthermore, in the solution we verified the possibility of simulation in a longer track section on which there are several railway stations due to the fact that when assessing the throughput performance of track sections we do not mean only the section between two adjacent railway stations. Longer sections, delimited by the so-called train stations. In this case, the situation is changing radically. Trains pass through individual sub-sections, which we consider to be separate - directly connected lines of public service. The above considerations apply to the first track section (A-B). However, random phenomena that have affected the ride in this section are transmitted to the following section. The train outputs from the previous section are thus actually inputted for the following section.

This fact is a decisive fact for the possibilities of modeling and simulation of traffic in track sections. The input stream of trains leaving the previous section can be used as the input stream of requests - trains to the following track sections. In this case, only the time of occupancy of individual sub-sections becomes a random variable [5]. With regard to the above starting points, the simulation of traffic in railway line sections depends on 3 basic parameters:

- train entry intervals to the track section - $t_i$
- time of occupation of the track section - $t_{obs}$
- the number of lines and stations on which the traffic will be carried out, which can be used for possible waiting of trains in the queue.

The decisive variable in the train traffic simulation is the occupancy time of the line section. The interval $t_{eq}$ is generally not considered a random variable. It follows that the random variable is only the driving time $t_j$. When looking for the distribution of a random variable describing the driving time $t_j$, we performed extensive statistical surveys on 18 track sections of The Railway of the Slovak Republic with a total of about 10,000 data. This statistical survey showed that the driving time is best described by Erlang's distribution of a random variable, which uses only two parameters a and b. The decisive empirical fact and scientific contribution was the discovery that the parameter is constant for all track sections, regardless of their length.

We performed the simulation verification according to the original algorithm. The situation was relatively simple in the case of a simulation on a one-way line section. The simulation on a single-track line section is much more complicated. The complexity is mainly based on the fact that trains enter the line section from both sides and it is necessary to constantly evaluate their position and solve their crossing at railway stations accordingly. The condition of
deterministic train entries is much more serious in this case, because the section cannot be congested in any case. Trains may enter only if the situation on the line section at least theoretically allows them to run smoothly, intersect and avoid. This situation will always be influenced by the employees of the operational management of railway traffic and therefore it is not possible to speak unambiguously about random - stochastic or deterministic train entries [8].

4. Conclusions

The above mathematical calculations were the input for the creation of a computer program that allows selection of a railway track section, choice of traction vehicle, entering changes to the displayed data on the track section according to the specific situation and possible disruption, proposal of measures with regard to the disruption of railway sections, calculation of detailed running times of a standard train in a selected track section, entering changes in the data on railway track sections according to a specific disruption, calculation of throughput performance in the restricted track section, transfer of data on railway track sections from superior database systems ZONA and EXPERT and addition, updating and repair of used databases [2].

All-important operational and technical information is displayed. The length of the sections, the type of safety device, the number of tracks in the stations, the driving times and the occupancy times of the sections and the maximum permissible performance which is decisive for the traffic orientation. The output gives a perfect picture of the possibilities of transport use of individual inter-station sections. This information was also the input for the next stages of the project.

The correct application of the program enables the railway control units to adopt the optimal variant of the solution and to prepare measures in advance that will minimize the negative impacts of crisis phenomena on the railway transport operation. The program was tested in cooperation with The Railways of the Slovak Republic and the military transport authorities of the Armed Forces of the Slovak Republic. It is used in teaching at the University of Žilina and is actually used by The Railways of the Slovak Republic dispatching apparatus. In solving the task of train traffic simulation in crisis situations, classical approaches to the organization of train traffic in track sections were used and at the same time traffic-technological starting points and calculations based on the original calculation of travel times and their simulation based on the minimum travel time by section were used and verified.

Acknowledgments

This work was supported by the research projects VEGA 1/0159/19 Evaluation of the level of resilience of key elements of land transport infrastructure” and by the European Union within the FP7 project No. 608166 “Risk Analysis of Infrastructure Networks in response to extreme weather”.

References

Research on Controlled Semi Active Suspensions in Passenger Car

N. H. Venkatesh¹, A. Darguzis²,³

¹Kaunas University of Technology, Studentu g.56,51424, Kaunas, Lithuania, E-mail: nalven@ktu.lt
²Kaunas University of Technology, Studentu g.56,51424, Kaunas, Lithuania, E-mail: andrius.darguzis@ktu.lt
³Kaunas University of Applied Engineering Sciences, Tvirtoves al. 35, 50155, Kaunas, Lithuania, E-mail: andrius.darguzis@edu.ktk.lt

Abstract

Emerging research in the field of vibration damping in transportation is inclined towards the advancements and improvements in the active suspension system. The magnetorheological fluid suspensions are under constant research to match their abilities to act as active suspension systems though they are semi-active suspensions. The limitations of this promising system are hard cake formation, sedimentation, clumping effect, fluid particle separation, oxidation of particles, behavioral stability at high temperatures [3, 4, 7]. In an attempt to reduce or eliminate the hard cake formation, this work has proposed magnetic particles suspended in the polydisperse phase containing micro and nano particles of nickel oxide in carrier oil. Nickel oxide eliminates the oxidation of particles experienced by employing Iron oxides. The traces of graphene were introduced to maintain the layer structure, thereby affecting the sedimentation and clumping effect properties of the magnetic particles. The rheological fluid properties were studied from the data incurred from the rheometer test. The size and arrangement of particles were analyzed under a scanning electron microscope. The damping properties of the proposed composition of MR fluid for different concentrations were tested experimentally using the quarter car model testing method using electro dynamic shaker, LABVIEW Software, data acquisition system, and accelerometers. Analytical simulation using MATLAB Simulink platform was performed to compare the analytical and experimental output. The obtained results verify that the proposed composition for the MRF damper successfully arrests the sprung mass vibration.

KEYWORDS: active suspension, magnetorheological fluid, damping properties, MATLAB, quarter car model

1. Introduction

Suspensions are the collective term assigned to the system consisting of the arrangement of the tires along with the linkages, springs, shock absorber or dampers that connect the vehicle frame to the tires. The suspension system integrates the relative motion that deals with the consistency of the ride experience between the car’s frame and the wheels. The suspension system provides vehicle handling parameters to the vehicle while cornering, maneuvering, and braking. Suspension’s birth was when high speed internal combustion engines came into existence. The speed range of IC Engines demanding a stability provider and load carrier. With the evolution and technological advancements, the suspension system has evolved from a simple linkage to an advanced complex technologically adjustable damping suspension which provides intelligent damping to the vehicle according to the ride conditions [1, 6, 10]. The active suspensions which can adapt to continuous changing requirements have revolutionized suspension. The application of active suspension systems includes the transport industry and civil industry [2]. The following research is based on the application of one of these active suspensions in the transport industry suited for passenger vehicles namely magnetorheological fluid dampers. With the recent inventions in material sciences, the composition of the MR fluid and its performance in this application was assessed and evaluated to conclude [8]. As denoted in the previous study MR fluid suspensions can be employed not as damper but also as impact absorbers for bumpers to avoid vehicle collisions [11].

2. Magnetorheological Fluid Preparation and Analysis

The research was to propose a new composition of MR fluid that cooperates with the advantages of employing magnetic particle polydispersity and stability of the fluid behavior. The elements were studied and analyzed for their behavior and properties. Substantiating properties and characters of the elements are furnished in researches [2, 4]. The preparation of the fluid was a sequential process involving multiple steps as discussed subsequently. The analysis of the particle and fluid was done experimentally to infer their properties using SEM and rheometer respectively.

2.1. Magnetorheological Fluid Composition

The composition calculations were with respect to the volume of the fabricated prototype model of the damper. To evaluate the performance and effect of material concentration on damping characteristics, three different
concentration of the same composition was prepared and analyzed. The proposed composition consists of nickel oxide and graphene suspended in a carrier oil with grease as a standard lubrication agent to achieve a viscous fluid as shown in Table 1.

### Table 1: Composition of the Magnetorheological Fluid

<table>
<thead>
<tr>
<th>Sample</th>
<th>Nickel iron oxide + Graphene composition</th>
<th>Silicone oil composition</th>
<th>Grease composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20% (7+1 g)</td>
<td>80% (32ml)</td>
<td>2.5 g</td>
</tr>
<tr>
<td>2</td>
<td>25% (9+1 g)</td>
<td>75% (30ml)</td>
<td>2.5 g</td>
</tr>
<tr>
<td>3</td>
<td>30% (11+1 g)</td>
<td>70% (25ml)</td>
<td>2.5 g</td>
</tr>
</tbody>
</table>

**2.2. Magnetic Particle Synthesis**

Nickel oxide has a magnetic response and oxidation of the particle under high temperatures does not occur as in iron oxides as they are stable metal oxides [12]. The nickel oxide magnetic particles were synthesized from nickel carbonate and ferric chloride. The nickel carbonate and ferric chloride molar solution were prepared in the 1:2 ratio respectively according to their molar weights. Alginate is dissolved in ammonia which is added to the prepared solution to act as a binding agent. Triton X 100 is used as a buffer solution and nonionic surfactant.

The solution is heated for about 6-8 hours until the water content evaporates to form coarse crystalline Nickel oxide. The top down synthesis method in which continuous thermal energy is applied to the material to reduce its particle size is chosen to obtain the desired form of magnetic particles. The crucible containing the coarse crystals is heated in a muffle furnace for 8 hours at 300°C, 500°C, 700°C, and 900°C. After completion of each stage of temperature in the muffle furnace the crystals are crushed and churned using mortar and pestle. The synthesized nickel oxide particles are weighed, shown in Fig. 1 and stored in a container.

**2.3. Graphene Preparation**

Graphene exhibits excellent mechanical, electrical and magnetic properties [13]. Graphene can be derived from graphite at room-temperature by a low-cost strategy in which hydrogen peroxide, hydrogen sulphate or hydrochloric acid is added and heated until excess oxygen evaporates (Fig. 2). The addition of hydrogen peroxide releases oxygen which increases the space between the layer producing sheet like agreement of the atoms forming graphene sheets. The covalent Vander Waals force between any two carbon atoms in the structure is so strong that it is merely unbreakable under normal circumstances. Therefore, graphene will serve as a stabilizer that will greatly influence the magnetic field distribution in the medium along with the suspended particles preventing from clumping effect. It will also act as a surfactant because the structure can help to maintain the magnetic material dispersion in the fluid. The sedimentation properties of the fluid will be altered and improved by employed graphene sheets.

**2.4. Magnetorheological Fluid Preparation**

The synthesized nickel oxide and graphene were weighed and added in three different beakers that were labeled with respect to their composition. The silicone oil for each sample was measured and added. Grease was measured as a standard quantity lubricant to achieve the viscous liquid for all the samples. Each of the samples was stirred physically to dissolve huge lumps. Further the dispersion of the magnetic particles in the carrier oil was accelerated using a magnetic stirrer. The magnetic pellet was dropped into each beaker containing the samples. The magnetic stirrer is turned on and the RPM is set to the desired level. Each sample is magnetically stirred at 1100 RPM for about 6-8 hours until it forms a uniform viscous liquid. The samples are then kept in the ultrasonicator for 4-6 hours to achieve complete dissolution of solid particles in liquid and to remove disruptions and trapped gases in the fluid. Each fluid sample was
transferred to the cylinder while performing the quarter model tested to obtain the vibrational performance data.

2.5. Particle and Fluid Property Analysis

The synthesized nickel oxide particles were observed under a scanning electron microscope to evaluate and understand the particle size, arrangement, and shape. The observation was done to determine the properties exhibited by the nickel oxide particles when a magnetic field is applied. The fluid samples containing the dispersed particles at different concentrations were subjected to rheometer testing to analyze and study the rheological properties of the fluid under ambient conditions keeping information from hysteresis of MR fluid study as a reference [9]. The fluid behavior of non-Newtonian fluid samples can be determined with the obtained results.

**Scanning Electron Microscope**

The specimen being a non-biological component, the accelerating voltage was maintained a constant at 20 kilovolts (kV) and the magnification of the image was increased at each step. The images were captured at x10000, x20000, x30000, x55000 that are shown in Fig. 3, a-d. The images prove that the magnetic particles are in a polydisperse state where both micro and nano particles of nickel oxide coexist. The coexistence of nano and micro particles in an MR fluid has significant benefits. The exhibited structure can greatly eliminate the hard cake formation of these particles when subjected to periodic magnetization as a magnetic particle suspended in MR fluid as indicated in a previous study [7].

**Rheometer**

Rheometers are devices used to determine the rheology of fluids. The process that involves the study of behavioral changes of fluid to applied forces is called rheology. Rheometers are of two types: shear and extensional rheometers. The parallel plate shear geometry rheometer was used to obtain shear stress, shear strain, the viscosity of the fluid at the constant rotational speed of the plates with respect to time. A graph of the required data was obtained from which the exact numerical data can be arrived and tabulated. The values are plotted as a graph against the analyzing parameters. The relationship between the shear stress and shear rate for the studied samples at 25°C obtained from different shearing times, under increasing and decreasing ramp in shear stress is shown in Fig. 4. It should be remembered that the shear flow curve under the rising ramp in shear stress is greater in all samples than that obtained under the decreasing ramp. During the increasing ramp in shear stress, the structure and the flocculants of the fluid breaks down and decreases further when the shear stress is increased as shown in graphs Fig. 4. Conversely, lowering the stress rate during the reverse process will induce flocculant growth and allow the particulate network to recover the expanded stress spectrum examined, suggesting that the fluid was stable during the experimental study. The increasing stress range investigated, indicates that the fluid was stable during the experimental work. The fluid behavior was close to a Newtonian fluid.
3. Magnetorheological Fluid Damper Fabrication and Testing

3.1. Damper Fabrication

The fabricated MR damper setup consists of the following parts which are assembled as a damper setup for the testing purpose - cylinder, cylinder head, piston rod, piston head, coil windings, and base plate. The cylinder was machined and drilled which contains two layers of walls inside. It allows a nylon sleeve to insulate the inner cylinder as it will be subjected to a magnetic field. The cylinder and cylinder head were made of cast iron to withstand high temperatures. The piston ring and piston head were made of aluminum which houses the coil wires and windings respectively. These were assembled to obtain the prototype of the MR fluid damper as shown in Fig. 5. The volume of the cylinder is calculated based on the dimensions of the prototype as shown:

$$\text{Volume of cylinder} = \pi r^2 h = 3.14 \times 20^2 \times 80 = 100,480 \text{ mm}^3 = 100.48 \text{ ml};$$

$$\text{Volume of damper} = \pi r^2 h = 3.14 \times 15^2 \times 37 = 26,140.5 \text{ mm}^3 = 26.14 \text{ ml};$$

$$\text{Volume of MR fluid} = \text{Volume of Cylinder} - \text{Volume of Damper} = 100.48 - 26.14 = 74.34 \text{ ml}.$$

However, only half the damper must be filled with MR fluid. Therefore, 37.17ml of MR fluid is required.

3.2. Testing

The damper was subjected to vibration in real time to determine the working performance. The evaluation of the outcome of the real time experiment reflected the adaptability and ability under the experimental conditions. The experimental data needed analytical verification of the model. The output of the experiment was derived as the data for the analytical verification as discussed below.

**Experimental Testing**

The experimental testing of the damper consists of a setup that includes various components namely the quarter car model, power amplifier, data acquisition card, accelerometer, regulated DC power supply, vibration shaker machine, cooling system and a system with LABVIEW software [5, 7]. The quarter car model consists of the sprung mass housing in which the fabricated damper is fastened to the vibrational shaker that provides the disturbance to the system that is required for vibrational analysis as shown in Fig. 6. The power amplifier was used to control the frequency levels to excite the vibrational shaker as shown in Fig. 7. An accelerometer was installed in the top plate of the vibrational quarter car model which acts as the base of the sprung mass. The accelerometer receives the vibration or acceleration of the vibrating plate which can be monitored and recorded using the data acquisition card and LABVIEW signal express software. The vibration of the top plate was recorded from the LABVIEW software for every 2 Hz from 2-20Hz for each sample. These vibrations recordings were then analyzed by converting the accelerating values of the plate into vibrational displacements as shown in Fig. 8. The converted displacements signals and the respective values were noted.

![Fig. 4 Shear Stress Vs Shear Rate of Sample 1,2,3](image)

Fig. 5 Fabricated Damper

Fig. 6 Quarter Car Model

Fig. 7 Vibrational Amplifier and Signal Recorder
and tabulated as shown in Table 2. The obtained values of the displacement for each sample at a different input voltage of the coil winding of the damper is plotted against a graph.

![Fig. 8 Conversion of Vibrational signals into Vibrational Displacements](image)

<table>
<thead>
<tr>
<th>Displacement of Sample 1</th>
<th>Displacement of Sample 2</th>
<th>Displacement of Sample 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hz</strong></td>
<td><strong>5V</strong></td>
<td><strong>10V</strong></td>
</tr>
<tr>
<td>8</td>
<td>1.663</td>
<td>2.136</td>
</tr>
<tr>
<td>10</td>
<td>0.895</td>
<td>1.242</td>
</tr>
<tr>
<td>12</td>
<td>0.514</td>
<td>0.668</td>
</tr>
<tr>
<td>14</td>
<td>0.398</td>
<td>0.583</td>
</tr>
<tr>
<td>16</td>
<td>0.344</td>
<td>0.626</td>
</tr>
<tr>
<td>18</td>
<td>0.192</td>
<td>0.228</td>
</tr>
<tr>
<td>20</td>
<td>0.165</td>
<td>0.204</td>
</tr>
</tbody>
</table>

![Fig. 9 Displacement Vs Frequency of Samples](image)

The displacement graph plotted against the frequency for each input voltage of the coil winding explicitly proves that the vibrations are arrested considerably as shown in Fig. 9. The lower frequency damping was observed to significantly better at higher input voltages as the vehicle body resonates at a similar range. The damping ability of sample 1 is significant when 10V input is given. Similarly 5V and 15V for samples 2 and 3 respectively. Thus the vibrational damping properties of the samples were analysed experimentally.

**Analytical Analysis**

Using MATLAB Simulink, the semi active suspension experimentally tested by the quarter car model was created as a Simulink model for analytical verification as shown in Fig. 10 [5, 11]. The values of k/m and c/m which are derived from the graphs are fed as input for the created Simulink model in MATLAB tabulated in Table 3.
Table 3

<table>
<thead>
<tr>
<th>Input voltage</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5V</td>
<td>8</td>
<td>4.4</td>
<td>3.6</td>
</tr>
<tr>
<td>10V</td>
<td>6.2</td>
<td>3</td>
<td>5.6</td>
</tr>
<tr>
<td>15V</td>
<td>3.8</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>20V</td>
<td>4</td>
<td>3.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Fig. 10 MATLAB Simulink Model and Generated Waveform

The obtained results of the MATLAB Simulink model using analytical approach and quarter car model testing by the experimental method proved to have similar vibrational damping patterns. The generated waveform in MATLAB is shown in Fig. 10.

4. Conclusion

In this research, the proposed composition of MR fluid eliminates certain limitations faced in previous fluid proportions such as the hard cake formation, clumping effect, and sedimentation. The polydispersity observed in the SEM results shows that it will considerably affect the hard cake formation due to the presence of both micro and nano particles in them. The graphene proved to have improved the stability of the MR fluid exhibiting damping characteristics at different frequencies. The structure of graphene contributes to maintaining the fluid particle deposition and clumping effect by acting as a surfactant. The particle and fluid analysis were carried out experimentally to substantiate the furnished results by SEM and rheometer testing. The performance of the MR fluid in the damper prototype carried out experimentally using a quarter car model concept shows a significant reduction in the amplitude of vibration of the sprung mass of the vehicle. The damping displacement graphs of all the samples embrace that the designed system employing the prepared MR fluid successfully isolates vibration in real time that will offer improved vehicle stability and ride comfort. The testing conducted on the different concentrations of the fluid experimentally proved the efficiency of the concentrated samples at higher input voltages. To conclude, a higher concentration of this MR fluid damper can be utilized for heavy loading conditions whereas the lower concentrations can be used for relatively low frequency loading conditions.

5. Future Scope

The research holds a huge scope for further development in different aspects as this study was mainly aimed at evaluating the new fluid composition and response. The damper model can be modified by using alloy to relatively decreasing the weight, stroke length can be increased to produce better damping results for a luxurious ride, the study can be conducted on a twin tube MRF damper and bore diameter can be increased to withstand high temperatures. The coil windings employed in this research can be replaced by thicker wires that can be used for high range magnetization. The system can be improved if a smart control system for input voltage can be introduced. Self-altering voltage or coil method can be considered while designing the damper prototype. The comparative study of polydispersed magnetic particle and nano magnetic particle can be conducted to evaluate the effect of size and arrangement of particles in MR fluid damper. There still exists a scope to improve the stability of the fluid by determining the effect of different surfactants for varied applications to achieve the appropriate performance output.

References

Customer Perspective of the BSC System in Strategic Management of Bus Transport Enterprises in Slovak Republic

E. Kicová1, O. Ponisciakova2

1University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak republic, E-mail: eva.kicova@fpedas.uniza.sk
2University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak republic, E-mail: olga.ponisciakova@fpedas.uniza.sk

Abstract

Strategic management is an essential part of business management. It is a way to increase the competitiveness of businesses. One of the possibilities of using strategic management tools in bus transport companies is the concept of the Balanced Scorecard (BSC) system. The BSC system consists of four perspectives - financial, customer, process and learning and growth perspectives. These perspectives use various indicators that need to be respected when implementing a BSC system in a company. In our paper, we will point out the customer perspective of the BSC system through a questionnaire survey on a selected sample of passengers. We also analyzed how companies in the Slovak Republic use the BSC system in strategic management and the results of the survey are part of this paper.

KEY WORDS: strategic management, BSC customer perspective, bus transport enterprises

1. Introduction

Modern methods of corporate governance require the adoption and implementation of such measures, which change the usual views and practices in favor of increasing the efficiency and competitiveness of the company in the field of the market economy. The concept of the BSC system combines a number of known and proven elements of management with new approaches to the implementation of the strategy, and thus contributes to the fulfillment of the company's mission. Today, this strategic tool is increasingly popular in the world. Owners, managers, but also the executives of many companies themselves appreciate its contribution to the prosperity of the company and the fulfillment of the goals not only of the company as a whole, but also the personal goals of the employees themselves. Thinking in terms of individual perspectives of the BSC system, emphasis on non-financial aspects of the company's activities and a logical approach in terms of acceptance of cause and effect relationships in the company will guide the company to successfully achieve its mission and vision and thus represents a new management tool in bus companies.

2. BSC System and its Strategic Management Concept

The Balanced Scorecard is a management method that adds other aspects to the traditional view of evaluating the company's performance through a financial scale, which expresses the driving forces of the company's future performance [1].

Wang argues that a manager must consider these basic principles when measuring an organization's performance. Measure the right elements - the system must measure activities that directly support the productivity of the organization. Communicate clearly what is being measured - gauges that are insufficiently defined or poorly communicated will not be used or understood by employees. Consistent application of measuring instruments - indicators must be consistent with each department in the organization, otherwise there is a risk of losing support for the entire measurement system. Keep meters active - indicators must be used constructively. The non-use of the results according to Wang measurements result in an identical conclusion - insufficient support for the business performance measurement system [19].

In one study by Beard, the term "business scorecard" appeared. In addition to traditional financial measures, it also included measures relating to delivery times, the efficiency of new product development and production cycles. The discussion resulted in the extension of the scorecard to the Balanced Scorecard, composed of four perspectives, namely financial, customer, internal processes and learning and growth. Ultimately, [2] of the Balanced Scorecard, as an improved measurement system, a key management system capable of using BSC not only to clarify and formulate strategy, but also to manage it, has developed.

According to Beard, the methodology takes into account the basic vision of the company, which must be formulated precisely. It then defines four strategic areas that are involved in planning this vision or visions. These areas are finance, internal processes, learning and growth, and of course customers [3].

Some authors argue that the BSC methodology was primarily designed for large companies, but it can also be implemented in a medium-sized company. The different aspect is that for large companies the main motivation for the implementation of BSC can be to obtain a detailed picture of the company, for companies of medium or smaller nature, the main motive is to build a vision and related goals. However, it is important that in medium-sized companies, due to poor implementation, the BSC methodology does not become a bureaucratic tool by which the company loses flexibility [4, 12, 17, 18].
Horváth argues that the strategy model can only be complete if it answers questions about important areas of business. The setting of financial targets is insufficient unless the key objectives to be achieved are identified at the same time. It also considers a separate target setting to be ineffective. Thus, the interaction of goals is neglected. The requirement is then interrelated with all important aspects of the company's activities [10].

The authors Bhagwat and Sharma state that the compilation of the BSC methodology is relatively complicated and time-consuming in practice and requires a good orientation in the processes related to the company and its implementation can be very expensive in practice and personnel and organizationally demanding [5, 11, 16]. The authors Fibírová and Šoljaková say that the BSC methodology emphasizes that financial and non-financial measures should be a part of an information system that is accessible to employees at all company levels. It is important to be able to translate intentions and goals into concrete measures so that employees understand the financial implications of their decisions. Top management must understand the driving forces that ensure the long-term financial success of the company and the ability to communicate clearly in the company must be ensured [7, 14, 15].

The very name of the methodology suggests that it is a balanced, balanced scorecard. In real terms, this means that the individual KPIs need to be linked by relationships and ties that determine how these indicators interact and influence each other, and how they act and influence the overarching strategic goal in each perspective. The graphic result of this project is a strategic map of the company [6, 8, 9, 13].

3. Use of BSC System and its Perspective in Strategic Management in SR Companies

According to Sancho, the Balanced Scorecard method is becoming increasingly popular among companies around the world. According to a survey by Bain & Company, which annually evaluates the use and effectiveness of management tools among organizations around the world, the BSC system has recently been revised to 5th place in the ranking of the ten most used management tools [17].

In connection with this finding, we were interested in the current position of the BSC system in Slovakia. We therefore decided to conduct a survey in order to clarify the use and knowledge of this important management tool among organizations in the Žilina region.

Population, i.e. The statistical set, which is defined by the aim of the survey and for which we conclude, were business entities operating in the territory of the Žilina Region. We carried out the survey in the period from January to August 2019 by means of a questionnaire sent to the respondents in accordance with the conditions of random selection according to Rimalčík, i.e. the probability of being included in the sample was the same for all statistical units of the population and the statistical units were sampled independently of each other. The sample represents the part of the population that we examined and for which we have data, and if the rules for selecting statistical units for the sample are chosen in accordance with the theory of probability, we can generalize the results found in the sample to the whole population [16].

The questionnaire was intended for the management of the addressed subject and contained closed 9questions with the possibility of 1 or more answers, while some questions allowed to comment on the issue under the option “other”. Respondents were contacted via a telephone call or by sending an e-mail containing an Internet link to www.thesistools.com, where the respondent could conveniently fill in and send the questionnaire. Contacts for organizations were obtained through a thorough, but in principle simple search on the Internet. 62 subjects were contacted and the rate of return reached the level of 77%.

The first three questions of the questionnaire were focused on the identification of respondents. We were interested in the number of employees, the amount of annual turnover and the sector of the national economy in which the organization operates. In terms of the number of employees’ criterion, 21 small enterprises with the number of employees up to 50, 15 medium-sized enterprises with the number of employees from 51 to 250 and 12 large enterprises with more than 250 employees participated in the survey.

According to the size of the annual turnover, the largest part (44%) were enterprises with an annual turnover from 10 to 50 mil. € and the other two categories were both the same size of 28%, companies with an annual turnover of up to 10 mil. € and also companies with an annual turnover of over 50 mil. €. In terms of the type of activity performed, the primary sector was represented by 6 organizations, the secondary sector by 21 organizations, the tertiary sector 19 and 2 organizations came from the quaternary sector of the national economy.

In the fourth question of the questionnaire, we asked the respondents which management tools, or more precisely methods they use. The starting point for their assignment was a Bain & Company report published under the title "Management Tools and Trends 2019", which annually evaluates the use and satisfaction with 25 popular management methods around the world. At present, the company has more than 12,000 contacts for respondents, which allows it to systematically determine the effectiveness of globally used management tools. For the purposes of our survey, we gave respondents a choice of the 10 most used management tools in 2019 according to the above report, namely: Balanced Scorecard, Benchmarking, Change Management Programs, Core Competencies, CRM, Employee Engagement Surveys, Mission and Business Formulation, Outsourcing, Strategic Planning and Supply Chain Management. To these, we added other, in our opinion important, tools, which are Process Reinengineering, Customer Segmentation, Open Innovation, TQM and respondents could list other management tools used by them under the option of "other".

We found out that small businesses use an average of 3.2 management tools per business, medium-sized businesses use 3.5 tools, and an average of 8.2 tools help large business managers to run the business. Organizations in
the Žilina Region use Outsourcing (73%), CRM (69%) and Strategic Planning (64%) the most. Of the listed tools, Change Management Programs (0%), Balanced Scorecard (4%) and Process Reengineering (4%) are used the least. Respondents did not mention any other tool in the "other" option.

With the fifth and sixth questions of our questionnaire, we asked whether companies set long-term goals, if so, in what area and whether they have a strategy to achieve them. The seventh to ninth questions directly concerned the Balanced Scorecard system, its use or non-use.

Based on the respondents' answers, it can be stated that companies set long-term goals, but only 20% of respondents also have a set strategy for achieving them. As many as 72% of companies said they did not set a strategy and 8% of survey participants used the "don't know" option. Sadly, despite the fact that up to 48% of companies set long-term goals in both financial and non-financial areas, only 4% of them use the Balanced Scorecard system, which, given the size of our sample, represents 2 organizations. From the question "What do you see as the biggest difficulties in implementing BSC", we received the answer that the biggest difficulties were with clarifying the strategy, strategic goals, objective indicators and actions (1 respondent) and implementing the system throughout the company (1 respondent). Other respondents cited satisfaction with the current management system, which they do not plan to change (36%), high financial, organizational and time demands (32%) as a reason for not using the BSC system, and 24% of respondents admitted that they did not recognize this system.

We also found out the importance that Slovak managers attach to individual criteria. Only those who knew the BSC system answered this question. It can be stated that up to 34% of them consider the financial perspective to be the most important, 28% the customer perspective, 26% the internal process and only 12% consider the learning and growth perspective to be the most important. However, the explanatory power of this question is limited because it is usually associated with the position of the manager who answered the questionnaire.

The process of inductive statistics according to Rimalčík [16], i.e. the process of generalizing judgments about population characteristics according to information from a random sample, is based on standard errors, while the standard error of statistics decreases with increasing sample size.

We are aware of the fact that the size of the random sample we selected is relatively small compared to the size of the base set, i.e. population, thus increasing the magnitude of the standard error. Also, the 77% return of the questionnaire can be considered a satisfactory number, but from the point of view of the use of probability theory it is insufficient. However, the aim of our survey was not a detailed knowledge of the issue of Balanced Scorecard in the conditions of the Slovak Republic, our goal was to point out to what extent the system of BSC is known to managers of organizations, or more precisely to what extent they use it.

As follows from the survey, knowledge of the BSC system in the conditions of the Slovak Republic is at a relatively low level. Although almost half of the respondents are aware of the importance of not only financial but also non-financial targets and indicators, almost a quarter of respondents have never heard of the BSC system, so they cannot assess and take advantage of the benefits of this globally recognized management tool.

4. Customer Perspective of the BSC System in the Bus Transport Enterprise

An important part of the BSC system is the creation of a strategic map for the bus transport company. For this reason, it is necessary to analyze all perspectives and design an optimal strategic map for the bus transport company, which will accept the specifics of the bus transport business.

The result of defining individual perspectives is the creation of a strategic map (see Fig. 1). From our point of view, a bus transport company can be "inspired" by a strategic map created by us, which reflects the specifics of business in passenger bus transport. However, we point out that in practice it is necessary to create your own strategic map, which respects the defined vision, mission and goals of the company. We believe that this proposal provides sufficient guidance on how to create your "own".

The creation of a strategic map provides the basis for the creation and subsequent use of the BSC system concept in a bus transport company.

From our point of view, we will pay more attention to the customer perspective of the BSC system. It is easy to define criteria that, from the customer's point of view, will bring customers a satisfactory experience, which will ultimately result in an increased number of transported customers and contribute to maintaining the loyalty of regular customers.

It is for this reason that during September, October and November 2019, we conducted a survey among passengers in suburban and long-distance bus transport in the Žilina region. The survey was conducted through a questionnaire personally by full-time students of the Department of Economics and Business Management. We received a total of 225 respondents who were willing to answer questions about travel satisfaction. We divided these respondents according to age into three generations. Generation X was a passenger older than 60 years. Generation Y passengers aged 60-40.5 years and Generation Z passengers over 25 years. We assumed that workers and students most often use suburban and long-distance transport, which was also confirmed to us. Of the total number of respondents, 15% were representatives of generation X, 52% were representatives of generation Y and 32% were representatives of generation Z.

We directed the level of customer satisfaction mainly to the technical condition of the bus, its equipment and service. Passengers were to indicate their satisfaction with the bus equipment and its technical condition on a scale of 1 - 3. There was also a space in this question where they could justify their opinion (Fig. 2).
Only 28% of respondents were satisfied with the technical condition of the bus. A significantly high percentage of respondents said they were less satisfied and only 12% were dissatisfied. From the point of view of individual generations, the most satisfied were passengers older than 60 years, the least satisfied were passengers from generation Y, which, however, could also be caused by the fact that they most often use this type of transport. We also looked at the level of satisfaction in terms of travel frequency. We divided the individual passengers into 5 groups (Fig. 3).

As can be seen from Fig. 3, it can be stated that with the increasing frequency of use of services provided by bus transport companies, the level of passenger satisfaction decreases. From the point of view of the technical condition of buses, the most common shortcomings identified by individual passengers can be considered to be their cleanliness, air conditioning and the friendliness of the driver. Other factors were most often regularity of connections and delays. From the point of view of the analyzed XYZ generations, it can be stated that the Y and Z generations travel the most, and also these generations were dissatisfied with the offered services.
5. Conclusions

In the article, we pointed out the wide range of uses of the BSC system in bus transport companies. In particular, we have outlined the issue of the customer perspective, which from our point of view is important both from the point of view of the customers themselves and from the point of view of the customers of bus transport companies. The current trend in the market economy is dynamic and unpredictable. The current "trampled" economy has literally been slowed down by a pandemic called Covid-19. What future developments will be very difficult to predict in the current situation. However, it is necessary to find new solutions that will either lead to a change in the system to which we are "accustomed", or more precisely it will be necessary to "start" new demand and supply. One of the possibilities is also new technologies, which can also change the whole direction of currently managed bus transport companies in the field of transport. For this reason, however, it will be necessary to review the entire management and strategic management of these companies. For this reason, we draw attention to the methodology of the BSC system, which is not a complete solution, but its use, or more precisely the use of its methodology can help to gain a competitive advantage and the right strategic position in the field of bus transport.

Acknowledgements

This work has been supported by the institutional (granted by Ministry of Education) VEGA Behaviorism in a socially responsible communication strategy of enterprises.

References

Modelling and Experimental Assessment of Dynamic Parameters of Mobile Robot Chassis

M. Vabolys\(^1\), P. Šaulys\(^2\), S. Niauronis\(^3\), G. Stonys\(^4\)

\(^1\)Alytus State College, Studentų st. 2, LT-62252, Alytus, Lithuania, E-mail: mykolas.vabolys@stud.akolegija.lt
\(^2\)Alytus State College, Studentų st. 27, LT-62252, Alytus, Lithuania, E-mail: povilas.saulys@akolegija.lt
\(^3\)Siauliai State College, Ausros al. 40, LT-76241, Siauliai, Lithuania, E-mail: s.niauronis@svako.lt
\(^4\)Alytus State College, Studentų st. 27, LT-62252, Alytus, Lithuania, E-mail: gintautas.stonys@akolegija.lt

Abstract

A mobile robot wheeled chassis was designed and prototyped. Its dynamic properties were estimated by calculations and checked by experimental trials. Construction is original by its design, components and other features, so to calculate dynamic characteristic parameters in the cartesian axis, a mathematical model was designed. Using this model, resisting forces were calculated for the case when the road surface is non-deformable. Maximum speed, acceleration and other parameters were determined using experimental trials and compared to model estimations. Experimental and theoretical results are comparable, probable origins of differences explained.

KEY WORDS: mobile robot, wheeled chassis, modelling of dynamics

1. Introduction

Use case variety for robots is expanding very rapidly, so more and more engineers and researchers are working in creating platforms for robotics. In Europe, 1% of workers is already a robot. A similar percentage is for the global situation. Some the countries have as high as 3% (Germany) or even 7% (South Korea) quantity of robots in the industry [1]. Industrial robots are already quite sophisticated systems (56% are being sourced from Japan) with good flexibility and reliability. But the industry is not the only area for robot use, where factories benefit from robot precision, velocity and absence of social problems with low-qualification work force. Other uses for robots also exist. E.g. in research, work in harsh conditions, military applications, logistics, health-care, etc. Most of these cases require mobility, which leads to the research of various types of movement according to required grip and traction specifics.

In military applications, the main purpose is to provide safe intel material without risk to human life. Also to neutralise potential hazards, such as explosives or enemy troops [2, 3]. For these purposes, crawling, tracked, stepping, wheeled or other – terrain based movement types of robots are important as they can have more carrying force with lower noise and battery consumption in comparison to frequently used drones. Ground based robots also have better hiding opportunities because of the low need for environmental clearance and better manipulation force because of friction to ground. Their remote-control operation can be paused for the long term and resumed on necessity [2]. Such use cases are already widely used in countries, investing in military applications, such as USA [3].

On the other hand, in Lithuania there are not many of well designed universal mobile robot platforms. Most the applications are using third party platforms, which might be a good choice for industrial or research applications, but not acceptable in case of use in military, because of possible shortage during periods of high demand (i.e. during geopolitical events). More to that national based platform has the advantage of fast adaption to different needs on demand and has a lower possibility of enemy-well-known imperfections or bugs as in the case of the mainstream products. This is why scientists, researchers and enthusiasts of Alytus College are developing mobile robot chassis suitable for national use.

While creating such a platform, it is important not only to create prototypes, but also to model their characteristics to understand underlying physics. This allows us to estimating possible load capacity, stability, velocity and other most important parameters when using the platform for a particular application.

2. Investigation of Dynamic Parameters of Mobile Robot Chassis

Mobile chassis was designed using the AutoCad software packet and is presented in Fig. 1. Such a model allows fast geometric measures required for the mathematical model and fast export of part drawings.

Fig. 1 also shows the prototype view of real manufactured chassis, which was further used for experimental trials. The designed chassis contains these elements: steel housing, 260 mm diameter wheels with rubber tires, chain drive, planetary reducers, two electric DC motors, a semiconductor based power controller, a microprocessor based control system with custom firmware, a Bluetooth communication module, 12V DC sealed lead acid battery, and switched-mode power supply converter.

The housing contains a stainless steel shell and light-weight all-metal (steel and aluminium) frame. The platform size is 400 × 400 mm. Overall chassis weight is 40 kg. Two motors were used (one for each side). Forward and rear
wheels are connected using a chain drive. The chain is inside the chassis, so it has full protection from environmental disturbances. Such configuration allows this chassis to be classified as tank-type drive as turning movement is a product of differential velocities for wheels on the left and right side.

Creating active suspension holding components the main key was its constructive elements as reliable to as possible. Another important aspect is to determine chassis speed and equal movement because it is critical when explaining and describing dynamic processes of chassis and suspension functioning. Dynamic processes of chassis movement depend on a few factors: road surface, the interaction between resistance forces from the road. After the engineering mobile chassis prototype then the dynamic model is made.

The dynamic model of the mobile chassis is made when the appropriate method is chosen: structural scheme and etc. In Fig. 2 mobile chassis structural scheme has been shown.

When we have a mobile chassis structural scheme dynamic model is made. The mobile chassis dynamic model prototype is shown in Fig. 3.

Dynamic model that is shown, shows us dynamic forces which explain the reason for chassis movement. Fig. 3 represents shown symbol values: \( m \) – mobile chassis mass, kg; \( F_{B_v} \) and \( F_{B_h} \) – vertical loads that effects front and rear
1024 wheels; \( G \) – centre of mass; \( h \) – centre of mass height; \( F_w \) – air resistance, N; \( F_r \) – road resistance, N; \( F_f \) – rolling resistance, N; \( M_v \) and \( M_h \) – front and rear wheels torque when spinning, Nm.

When a dynamic model is formed, dynamic equations for calculating are created. Movement speeds, resistant forces and etc. Mobile chassis movement speed when driving on a smooth road is calculated, when a wheel dynamic radius is known. Wheel dynamic radius is calculated:

\[
r = 0.5 \cdot 0.0254 \cdot d_p + 0.94 \cdot h_p = 0.5 \cdot 0.0254 \cdot 7 + 0.94 \cdot 0.0729 = 0.15 \text{ m},
\]

where \( r \) – tyre dynamic radius, m; \( d_p \) – alloy diameter (inches); \( h_p \) – tyre height, m.

The tyre height is calculated using the formula:

\[
h_p = w \cdot \frac{h}{100},
\]

where \( w \) – tyre width, mm; \( h \) – height in percent.

Wheel diameter \( d = 0.26 \text{ m}, \) maximum engine revolutions with minimal load are equal \( 400 \text{ min}^{-1} = 6.66 \text{ s}^{-1}. \)

Mobile chassis speed is calculated using the formula:

\[
v = l \cdot n = 0.81 \cdot 6.66 = 19.57 \text{ km/h},
\]

where \( v \) – mobile chassis speed, m/s; \( l \) – mobile chassis wheel length, m; \( n \) – maximum engine revolutions with minimal load, s\(^{-1}\). Maximum revolutions with minimal load \( 400 \text{ min}^{-1} = 6.66 \text{ s}^{-1}. \)

When theoretical mobile chassis speed is calculated, then we can calculate resistant forces which effects our chassis. Wheel rolling resistance, air resistance, road surface resistance, momentum force. Wheel rolling force when moving on horizontal road is calculated:

\[
F_f = m \cdot g \left( 2 \left( \mu_s \cdot \frac{d}{2} + f \right) + c \right) = 30 \cdot 9.8 \left( 2 \left( 0.005 \cdot \frac{20}{2} + 0.5 \right) + 0.003 \right) = 2.49 \text{ N},
\]

where \( F_f \) – wheel rolling resistance, N; \( m \) – mobile chassis mass, kg; \( g \) – free falling acceleration is equal \( g = 9.8 \text{ m/s}^2; \)
\( d \) – axle diameter, mm; \( \mu_s \) – coefficient; \( \mu_s = 0.005; \) \( D \) – wheel diameter, mm; \( f \) – coefficient, \( f = 0.5; \) \( c \) is coefficient, \( c = 0.003. \)

Air resistance force is calculated using this formula [3]:

\[
F_w = 0.5 \cdot C_w \cdot S \cdot \rho \cdot \left( \frac{v + v_0}{2} \right)^2 = 0.5 \cdot 0.32 \cdot 0.08 \cdot 1.204 \cdot \left( 5.43 \pm 5.5 \right)^2 = 1.84 \text{ N},
\]

where \( C_w \) – nondimensional aerodynamic coefficient, \( C_w = 0.32; \) \( S \) – robot crosscut space m\(^2; \) \( v \) – robot speed m/s; \( v_0 \) – wind speed m/s, \( v_0 = 5.5; \) \( \rho \) – air density kg/m\(^3\), \( \rho = 1.204 \text{ kg/m}^3\)

Momentum resistance force is calculated using this formula:

\[
F_a = \delta_a \cdot m \cdot a_p = 1.24 \cdot 294 \cdot 0.73 = 266.1 \text{ N},
\]

where \( \delta_a \) – coefficient value; \( m \) – mass; \( a_p \) – acceleration.

If we want to calculate resistance force for momentum we have to find value for acceleration. Acceleration is calculated using this dynamic formula:

\[
a_p = \frac{1}{2} \cdot g \cdot \mu_s = \frac{1}{2} \cdot 9.8 \cdot 0.15 = 0.73 \text{ m/s}^2,
\]

where \( a_p \) – maximum allowed speed, m/s\(^2; \) \( g \) – free falling acceleration, \( g = 9.8 \text{ m/s}^2; \) \( \mu_0 \)–coefficient, \( \mu_0 = 0.15. \)

This dynamic formula shows mobile chassis maximum allowed acceleration. Even movement road resistance power \( F_w \) is calculated using this formula:

\[
F_w = F_f + F_a = 2.49 + 266.1 = 268.59 \text{ N},
\]

where \( F_f \) – wheel rolling resistance, \( F_a \) – momentum resistance.

When forces affecting the chassis are calculated we have noticed that forces when moving on a horizontal surface from 0 to 5 m/s there was no big difference in its movement, because resistance forces are quite small, it is
1,87 N. Theoretically speaking we can say that with more speed than 5m/s with resistance forces working chassis will move slower.

Moving on horizontal road mobile chassis is not only affected by outside forces but by inside forces as well. Inside forces are wheel torque and vertical loads on the axle. When wheels contact with the road and mass is taken into account friction force is created. The skid will appear wheel torque exceed tire grip with the road. Farther wheels contact with the road vertical force appears. The vertical force affecting the wheel is distributed equally between the front and rear axles. Forces that affect the front and rear axle are calculated:

\[
G_p = G \cdot \frac{l_h}{l_h + l_v} ; \quad G_p = G \cdot \frac{l_h}{l_h + l_v},
\]

where \(G\) – mass power, kg; \(l_h, l_v\) – distance from wheel axle to centre of mass.

If we take values into 9th equation, we can figure out, that front and rear axle affected by this amount of force 196.5 N. Further we calculate electric engine torque delivered to wheels. The torque that’s delivered to wheels is calculated:

\[
M_N = 9550 \cdot \frac{P_{ex}}{n_x} = 52 \text{ Nm},
\]

where \(M_N\) - torque, Nm; \(P_{ex}\) – effective engine power \((P_{ex} = 0.118 \text{ kW})\); \(n_x\) – maximum engine \((n_x = 1300 \text{ min}^{-1})\).

Maximum torque delivered to both wheels is 52 Nm.

3. Robot with Mobile Chassis Experimental Research

To verify the theoretical calculation of the speed of the prototype of the mobile chassis, special equipment is selected for experimental testing: mobile phone, mobile app, personal computer for data processing and road surface. The experiment will be carried out on a non-deformable road surface i.e. paved road surface. Asphalt road surface is shown in Fig. 4.

Asphalt surface is made of mineral materials and bitumen. Every component of this surface has different mechanical characteristics which may differ from temperature, time and pressure. During time of usage the surface affect by road vehicles load and climate factors. Asphalt and concrete road surface rolling resistance coefficient is 0.007-0.015.

For experiment we have to choose mobile phone which is needed to use an app called “Speedometer” for measuring speed and control of the chassis. Application "Speedometer" uses GPS transmitter data and registers driven distance, maximum speed, average speed and driving time. Mobile app "Speedometer" is shown in Fig. 5.
During experiment when using “Speedometer” app we got these results, they are shown in Fig. 6.
During experiment, driving on an asphalt road surface, the maximum measured speed was 10 km/h (2.8 m/s). The maximum speed was recorded after driven 0,06 km distance or 60 meters, the average speed is equal to 2 km/h. This experiment was done until we reached maximum speed.

![Figure 6: Mobile chassis experiment results on the asphalt surface](image)

Taking recorded data into account we can calculate mobile chassis acceleration when driven on the asphalt road surface. We also don't have to calculate maximum speed because it was recorded during the experiment.

Mobile chassis acceleration is calculated using experiment data:

\[
a = \frac{v}{t} = \frac{2.8}{3.24} = 0.86 \text{ m/s}^2,
\]

where \(a\) – acceleration; \(v\) – speed; \(t\) – time.

Chassis power is calculated using formula:

\[
P_T = \frac{m \cdot a_p \cdot v}{\eta} + \frac{F_F \cdot v}{\eta} = \frac{30 \cdot 0.73 \cdot 2.8}{0.85} + \frac{2.49 \cdot 2.8}{0.85} = 80.34 \text{ W};
\]

where \(P_T\) – engine power, W; \(a_p\) – allowed acceleration, m/s\(^2\); \(v\) – robot speed, m/s; \(\eta\) – coefficient, \(\eta = 0.85\); \(m\) – robot mass, kg; \(F_F\) – roll resistance force, N.

Received experiment results are compared with theoretically received results. Theoretical and experiment results graphically are shown in Fig. 7.

![Figure 7: Theoretical and experimental comparison graphic](image)

With received graphic results we can see that experiment results from theory differ two times. During experiment chassis drives 60 meters per 3.4 s with 2.8 m/s speed and theoretically it should do 60 meters per 11.1 s and with 5.4 m/s speed. So theoretically not taking any factors about conditions like resistance forces from road surface unevenness, the chassis goes slower than during the experiment.

4. Conclusions

1. After analyzing the designs of mobile chassis, it was noted that each chassis is exceptional: one for its
complex construction, control and programming, and the other according to the performance tasks performed.

2. To make dynamic model into the structure scheme has been subjected to theoretical dynamic calculations according to the flowchart. Theoretical dynamic calculations show that the mobile chassis is estimated to theoretically be able to move at a speed of 5.4 m/s under the influence of road resistance forces.

3. The accomplished experimental research of the mobile chassis selected road surface was obtained results and plot out a speeds time-dependent schedule. Based on the graphic results obtained, it is found that the experimental results of the study differ from the theoretical calculation results 2 times. During the experiment, the chassis travels 60 metres over 3.4 seconds in giving a speed of 2.8 m/s and theoretically travels 60 metres over 11.1 s speed in give 5.4 m/s. In theory, without assessing existing environmental factors, the chassis travels faster than during the experiment.

4. In order to achieve more reliable experimental test results, should be used precision data collection equipment, and as well as repeated in more all the times during experiment the same and even conditions.

References


Formation of the Concept in Introduction of Autonomous Vehicle within the Traffic Flow Complex Decision Making

R. Litvaitis\textsuperscript{1}, R. Makaras\textsuperscript{2}

\textsuperscript{1}Kaunas University of Technology, Studentų str. 56, 51424, Kaunas, Lithuania, E-mail: robertas.litvaitis@ktu.edu
\textsuperscript{2}Kaunas University of Technology, Studentų str. 56, 51424, Kaunas, Lithuania, E-mail: rolandas.makaras@ktu.lt

Abstract

The paper discusses the problem of autonomous vehicles, which are subject to high technological level hardware being developed by many scientists who cannot find the answer for integration within the traffic flow problem. After analyzing different points of view and generalizing the results of researches being made, a conclusion of indefinite input parameter complexity is done.

KEY WORDS: autonomous vehicle, traffic flow, integration, human driver, machine learning

1. Introduction

Autonomous vehicle technology has been highly developed towards the priorities of safety and speed. The problems which were discussed a decade ago are now transferred to a higher level and the sharpest points are being derived. The introduction of an autonomous vehicle which is, sooner or later about to take place, requires a period of integration. Knowing the procedures of any technology system makes the sight of any integration process to be treated as the basic challenge and a subject of an investigation to be done. The fact of traffic is not only a technological system, but also a phenomenon of having a strong influence from the field of cognitive psychology and sociology. The reader of the text is going to be acquainted with scientific investigations being made at the subject of the autonomous vehicle integration process given the look from different points of view. The major attention is paid to the factors of traffic safety and human–fault risks implemented in the movement of hybrid traffic flow.

2. The Works and Methodology Being Discussed

Most of the science material represents data and results, gained from the car–follow models in which parameters as distance determination and keeping, acceleration and breaking are investigated. These models are mostly used for traffic simulation at the microscopic level. In the scale most authors find them to work at a satisfactory level of trust. Nevertheless, in more modern scientific work, it is considered that it is not enough to seek and find the exact algorithm for an autonomous car to duplicate human driver behavior. This is usually lead from the reason that car–following models are designed to act as the result of a human driver action result – i.e. it does not examine the reasoning of the actions being done by the human driver, but only duplicates the action without any deeper analysis of its basis.

Autonomous driving technology can provide driver convenience and enhance safety by avoiding some accidents due to driver error. While building autonomous driving algorithms, one significant issue is to make the autonomous vehicle be able to emulate human drivers’ intelligence and driving styles. This will allow the passengers of the autonomous vehicle to feel more comfortable and convinced in the car’s ability to drive itself. Also, drivers of surrounding vehicles will be able to better predict and understand the autonomous vehicle’s behavior and more naturally interact with it. Therefore, it is desirable to train the autonomous driver with a human driver’s behaviors (Fig. 1) [1].

![Fig. 1 Autonomous Driver Model Development Approach [1]](image)

Another and more modern branch of science studies are made on the based on registering dynamic in-traffic parameters – lane keeping and cruise control. These parameters are usually registered by using car manufacturers installed lane keeping warning and cruise control systems. The branch of science studies is again of the car – follow
model type investigation of one car interaction in the traffic flow. Usually, the artificial neural network learning process is to-the-level successful, because the autonomous vehicle can imitate the just learned action in a few minutes of learning.

Most adaptive control systems use classical control theory-based models. Control theory has been proven to be very powerful only if the accurate vehicle and interaction models are built. However, it is complicated to build an accurate deterministic model of human traffic. What is more, the control theory-based ACC is built based on human’s pre-knowledge and understanding of driving. The real human driving data is usually not used in constructing the controller. Control theory has been proven to be very powerful only if the accurate vehicle and interaction models are built. However, it is complicated to build an accurate deterministic model of human traffic. What is more, the control theory-based ACC is built based on human’s pre-knowledge and understanding of driving. The real human driving data is usually not used in constructing the controller. [1]

The actual science practice in investigating one-way car – follow models is, of course, a necessity in developing the path to problems which are fundamental in the branch of autonomous car safety. Nevertheless, the one-way models have the property of being one direction channel without the feedback. Once the movement of vehicles in traffic is treated as none less social phenomenon (with its psychological dimensions) than technological, it is necessary to expect the feedback to be an unneglectable measure in a scientific prospect of view.

3. Traffic Safety Problems in Autonomous Vehicles

The major part of the interaction between an autonomous vehicle and the traffic surroundings is about making a trustful two-way connection between the vehicle and the people who are in the closest neighborhood of the way the vehicle is taking. One of the often found branches for problems while dealing with current state investigation is the disengagement mode. It is a state of the journey when the autonomous vehicle expects to be assisted by the person who is in the drivers’ position. The necessity for disengagement mode is, so far, not to be avoided.

The database includes data related to all disengagement reports that occurred during testing on CA public roads between September 2014 and January 2017 as reported by Bosch, Delphi Automotive, Google, Nissan, Mercedes-Benz, Tesla Motors, BMW, GM, Ford, Honda, and Volkswagen Group of America. This database lends itself to statistical analysis, and currently includes a total of 5,326 data points. In most instances, the AT disengagement does not lead to an actual accident. Manufacturers that are testing on CA public roads are mandated to update their disengagement list each year. This database includes both accident occurrences in which an AT disengagement occurred (as a simple data point), and situations in which the off-nominal condition of the disengagement did not lead to any serious consequence (the vast majority of them, considering that only 26 accidents have been reported so far). Each manufacturer provides data on the mileage driven each month, along with specific details related to each disengagement (e.g., weather conditions, a brief description of the cause of disengagement, road type, and other relevant information depending on the case) [2].

According to the Traffic Accidents Involving Autonomous Vehicle Database report, there is a possibility for a detail analysis of traffic accidents. Most of the accidents, analyzed in academic papers took place in a certain specific area where the concentration of autonomous vehicles being tested is comparably high.

Report of Traffic Accidents Involving Autonomous Vehicles Database: this database provides more descriptive and detailed reports for actual accidents (i.e., minor and/or major collisions with damage to public property and/or serious injuries to people) that occurred in the 2014–2017 timespan during testing of autonomous cars on CA public roads. Manufacturers include Google, General Motors, Cruise Automation, Delphi, and Nissan. The database at the time of publication of this work consists of 26 events. Due to their limited number, these occurrences can be analyzed in a deeper and more detailed context [3].

Analysis of the report [3] leads to a list of conditions for further discussion of the autonomous vehicle mode and at the moment of the accident, and therefore, the reasoning of the accident is made:

1. Conventional mode: indicating manual mode was employed before the collision;
2. Manual disengagement before collision: indicating the AT was disengaged by the driver on purpose before the collision occurred;
3. Manual disengagement after a collision: indicating the AT was disengaged by the driver on purpose after the collision occurred;
4. Autonomous disengagement: indicating the AT disengaged without intervention from the driver (i.e., actual AT disengagement);
5. Autonomous mode: indicating the AT was not disengaged during the accident sequence [4].

After an analysis of the given data is made, the necessity for intervention of a human driver is obvious. For further research, a presumption for the possibility of a human driver being eliminated is raised. At this point, the interaction among the autonomous vehicle and its surroundings is viral. Studies show that it is not enough for the autonomous car to be able to mimic human driver behavior, but it is required for an autonomous car to be capable of predicting potentially dangerous situations and be ready to make the right action in an unplanned context.

Autonomous driving technology can provide driver convenience and enhance safety by avoiding some accidents due to driver error. While building autonomous driving algorithms, one significant issue is to make the autonomous vehicle be able to emulate human drivers’ intelligence and driving styles. This will allow the passengers of the autonomous vehicle to feel more comfortable and convinced in the car’s ability to drive itself. Also, drivers of
surrounding vehicles will be able to better predict and understand the autonomous vehicle’s behavior and more naturally interact with it. Therefore, it is desirable to train the autonomous driver with a human driver’s behaviors. As it is impossible to have all possible traffic scenarios as training data, a learning-based autonomous driving algorithm should be robust enough to perform in untrained situations [1].

4. Autonomous Vehicle Interaction with Traffic

Once the demand for an investigation of human behavior towards the technological systems (and vice versa) is raised, the method of modeling can not be avoided. Various studies with the objective of setting the mathematical model for human interaction in traffic are made. After analyzing some of the cases, an intermediate conclusion is done – for the model to be (in some level) true, a set of conditions must be satisfied:

1. the models’ input parameters must consist of a wide range of behavioral parameters in mathematical expression – this hard to implement condition may be interchanged by the model’s ability to gather parameters from real traffic (learn);
2. the system must be capable of modelling input parameters so that output parameters correspond to human driver (or pedestrian) behavior and include the component, meant by sociological parameters, which include the traffic community properties
3. the accuracy of modelling results must be able to be checked with respect to real traffic situations since the model can not be taught to imitate all of the traffic situation range, it must be capable to make self-predictions and interpretations and it must be checkable.

In order to represent the different aspects of the human way of driving, a finite number of control actions need to be envisaged [5].

The challenge of autonomous vehicles, which promises great gains in human welfare through improved mobility, safety, and environmental impacts, brings to light fundamental challenges for cognitive science and artificial intelligence, not just in sensing and control (where machines may potentially exceed human performance – e.g., in response times), but in mimicking or seamlessly meshing with human behavior in driving interactions. The problem of understanding how we “negotiate” the traffic also provides a microcosm of deep questions concerning human social interaction and communication more generally [6].

In order to efficiently compute the prediction, the dynamics of traffic participants are conservatively abstracted to Markov-chains, i.e. the abstraction is complete. Additionally, the input dynamics of traffic participants, their interaction with other traffic participants and the probability of changing the lane are considered. In order to improve the traffic prediction, it is planned to learn the introduced parameters based on recorded traffic data in the future.

The adaption of the prediction horizon as well as the resolution of the discretized state space to certain situations (e.g. innercity/highway) is another line of future research. The approach can also be applied for conventional cars by exchanging the trajectory planner module by a trajectory estimator module. Thus, the safety assessment becomes a virtual co-pilot that warns the human driver in critical driving situations [7].

As seen in Fig. 2, the different cases of a lane change in multi lane carriageway are modelled in order to check the safety of an autonomous car capability to mimic human driver decision making. The result gives the view of lane change scenario not being safe as it deviates from the planned trajectory. The source claims the probability of an unsafe action and reaction from human drivers is high enough to be concerned about.

Fig. 2 Stochastic reachable sets for the lane change scenario. [7]
Traffic flow, being a multi-stage parameter object to model is proven to be by much of authors. The interactive driving of an autonomous vehicle is considered to need the so-called homogeneous integration.

Considering the traffic as a multi-agent system allows us to simulate a more realistic ambient traffic even in complex situations by initiating coordination of the traffic. The traffic can be coherent with a homogeneous integration of the interactively driven vehicle. Moreover, it is conceivable to develop dedicated tools for the creation of scenarios taking into account, not only the vehicles independently, but also the sets of vehicles with similar characteristics. The time devoted to the preparation of the experiments would then be reduced [8].

5. Conclusions

The concept for the problem of autonomous vehicle integration within traffic is a subject for the various investigations being done at different levels of detail. The precise formation of the subject is not yet found. The general statements on the autonomous vehicle and traffic interaction being a heterogeneous system and requiring a homogeneous type integration process is agreed to hold among the authors revised. A complex scenario of any type of intellectual system making controls of the autonomous vehicle must be included in practical tests for better detailing of the sharp traffic situations all of which can never be learned in advance.

References

Investigations of Short - Term Maneuvering Behavior of Vehicles Moving on Snowy Roads

M. Bogdevicius¹, D. Rozyte²

¹Vilnius Gediminas Technical University, Saulėtekio av. 11, 10223, Vilnius, Lithuania, E-mail: marijonas.bogdevicius@vgtu.lt
²Vilnius Gediminas Technical University, Saulėtekio av. 11, 10223, Vilnius, Lithuania, E-mail: daiva.rozyte@vgtu.lt

Abstract

The paper presents the results of vehicle dynamics moving on a snowy road with short-term maneuvering. A 3D mathematical model of the vehicle was developed to evaluate the interaction of the wheels with the road. Maneuvering a vehicle is a periodic rotation of the front wheels at a small angle (2 degrees) with a frequency of 0.7 Hz. Vehicle movement was examined when the front wheels were rotated five times. The kinematic and dynamic parameters of the vehicle are presented.

KEY WORDS: dynamics, vehicle, tire interaction, snowy road

1. Introduction

There is a constant focus on car accident prevention and traffic safety. Intensive pavement wastage has a significant impact on pavement quality. Road surfaces such as snow reduce driving comfort and safety. The slippery the surface – the worse the traffic conditions for fast-moving cars [1, 3, 5]. When a driver is forced to change direction under a certain road surface, it may not be so easy. Personal driving skills, vehicle characteristics, weather conditions, road surface conditions must be taken into account [2, 4, 6]. This study examines and describes the stability of a vehicle moving at a given speed and changing its driving trajectory under slippery road surfaces.

Research has often sought to avoid stability and lateral slip but relies on in-vehicle systems. The paper presents a model with a wheel rotation function and examines it on a snowy surface at different wheel rotation speeds and different vehicle motion improvements.

The research aims to determine the kinematic and dynamic parameters of a vehicle moving on a road surface covered with wet snow as the front wheels are briefly rotated according to the harmonic law with a small turning amplitude.

2. Mathematical Model of Vehicle

For the analysis, a model for simulating vehicle behaviour was developed based on the three-dimensional vehicle model. Fig. 1, a shown a 3D model of the vehicle and in Fig. 1, b and Fig. 1, c – a dynamic models of the front left tire and front right tire, respectively.

![Fig. 1 Dynamic model of vehicle: a – 3D model; b – a dynamic model of the front left tire; c – a dynamic model of the front right tire](image)

The system of equations of the three dimensional model of the automobile may be written as follows:

\[
[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = \{F(t, q, \dot{q})\},
\]

where \([M],[C],[K]\) are mass, damping and stiffness matrices, respectively; \(\{F(t, q, \dot{q})\}\) is nonlinear load vector; \(\{q\}, \{\dot{q}\}, \{\ddot{q}\}\) are displacement, velocity and acceleration vectors, respectively.

The longitudinal and lateral forces of the \(k\) – th wheel in the local wheel coordinate system are given by:
\[ F_{sk} = \mu_{0k} F_{sk} \left( \frac{\dot{\lambda}_{sk}}{\lambda_{0k}} \cos(\alpha_k) + \frac{\dot{\lambda}_{sk}}{\lambda_{0k}} \sin(\alpha_k) \right) ; \] (2)

\[ F_{sk} = \mu_{0k} F_{sk} \left( \frac{\dot{\lambda}_{sk}}{\lambda_{0k}} \sin(\alpha_k) + \frac{\dot{\lambda}_{sk}}{\lambda_{0k}} \cos(\alpha_k) \right) , \] (3)

where \( \lambda_{sk} \) and \( \dot{\lambda}_{sk} \) – longitudinal and lateral slip ratios, respectively.

\[ \lambda_{sk} = \begin{cases} \frac{s_k}{v_{rk}}, & \text{when } s_k > 0 \\ \frac{s_k}{v_k}, & \text{when } s_k \leq 0 \text{ and } v_k \neq 0 \end{cases} ; \] (4)

\[ \dot{\lambda}_{sk} = \begin{cases} \tan(\alpha_k), & \text{when } s_k > v_k \\ \frac{R_{rk} \omega_k \sin(\alpha_k)}{v_k}, & \text{when } s_k \leq v_k \text{ and } v_k \neq 0 \end{cases} ; \] (5)

\[ \lambda_{0k} = \sqrt{\lambda_{sk}^2 + \dot{\lambda}_{sk}^2}, \quad s_k = R_{rk} \omega_k \cos(\alpha_k) - v_k; \quad v_{rk} = R_{rk} \omega_k \cos(\alpha_k) , \] (6)

where \( R_{rk} \), \( \omega_k \) and \( \alpha_k \) – dynamic radius, angular velocity and slip angle of \( k \) – th tire, respectively; \( v_k \) – the longitudinal vehicle velocity; \( F_{sk} \) – the vertical (normal) force on the tire.

The friction coefficients of the \( k \) – th wheel are given by:

\[ \mu_{sk} = \mu_{0k} \frac{\dot{\lambda}_{sk}}{\lambda_{0k}} ; \quad \mu_{sk} = \mu_{0k} \frac{\dot{\lambda}_{sk}}{\lambda_{0k}} ; \quad \mu_{0k} = c_1 \left( 1 - e^{-c_2 s_{0k}} - c_3 \dot{A} \right) e^{-c_4 s_{0k} v_k} \left( 1 - c_5 \left( \frac{F_{sk}}{10^5} \right)^2 \right) , \] (7)

where \( c_i \) (\( i = 1, \ldots, 5 \)) are coefficients and they depend on the type of surface, \( F_{sk} \) is vertical force.

### 3. Numerical Simulation Results

The vehicle mass is 1455 kg and mass inertia moments are: \( I_{x,x} = 603 \text{ kgm}^2 \); \( I_{y,y} = I_{z,z} = 2012 \text{ kgm}^2 \). Research on the movement stability of the vehicle on the road surface when the speed of the vehicle is 90 km/h has been carried out. The analyzed road surface includes wet snowed.

The rotation of the front wheels about the vertical axis varies according to the harmonic law:

\[ \delta(t) = A_{\delta} \sin(\Omega t) , \] (8)

where \( A_{\delta} \) – amplitude of rotation angle of the wheel; \( A_{\delta} = 2 \frac{\pi}{180} \), rad; \( \Omega = 2 \pi f_{\delta} \) – angular velocity and \( f_{\delta} \) – frequency, \( f_{\delta} = 0.7 \text{ Hz} \). The coefficients \( c_i \) (\( i = 1, \ldots, 5 \)) are used to determine the coefficient of friction \( \mu_{0k} \) when the road surface is wet snow is equal to: \( c_1 = 0.1946, c_2 = 94.129, c_3 = 0.0646, c_4 = 0.003, c_5 = 15.0 \times 10^{-6} \).

The changes in the angles \( \varphi_x, \varphi_y, \varphi_z \) of the vehicle body about the axes Xc, Yc and Zc over time are given in Fig. 2.
Fig. 3 Phase plane of variables: the angular velocity-rotation angle of car body $\omega_x = \omega(\varphi_x), \omega_y = \omega(\varphi_y), \omega_z = \omega(\varphi_z)$

Time history of longitudinal (a) and transverse direction (b) friction coefficients in each wheel is shown in Fig. 4.

Fig. 4 Time history of longitudinal (a) and transverse direction (b) friction coefficients in each wheel

Time history of longitudinal (a), transverse direction (b) and vertical forces (c) in each wheel is shown in Fig. 5.
Fig. 5 Time history of longitudinal, transverse direction and vertical forces in each wheel: a – vertical force; b – longitudinal force; c – transverse direction force

Time history accelerations of the vehicle body in the body coordinate system Xc, Yc and Zc shown in Fig. 6.

Fig. 6 Time history accelerations of the vehicle body in the body coordinate system Xc, Yc and Zc

Vehicles moving on snowy roads and wet asphalt pavement are given in Fig. 7.

Fig. 7 Vehicle movement trajectories on snowy roads and wet asphalt

The results of a study of a vehicle moving on a snowy road with a short turn of the front wheels showed that the amplitude of oscillations of the body of a moving vehicle about its longitudinal axis increases. Although the angles of rotation of the front wheels are small, the wheel-moving force of a vehicle moving on a slippery snowy road increases. This increases the rotation of the body around all axles of the body. Due to increasing body oscillations, the left and right side wheels are subjected to different sizes of vertical wheel pressure, so the friction forces also change accordingly.

4. Conclusions

Investigations have shown that at higher wheel turnaround times, vehicle movement is unstable, i.e., the vehicle slips off the road. The reduction of body vibrations is influenced by the stiffness of the vehicle's suspensions. The unevenness of the road surface when the vehicle is moving in this regime increases its instability.

References

3. Ruzinskas A.; Sivilevicius H. Magic formula tyre model application for a tyre-ice interaction, Procedia
Engineering 187: 335-341.


5. **Sokolovskij E.** 2007. Automobile braking and traction characteristics on the different road surfaces, Transport 4: 275-278.

Calculation of Transverse Horizontal Forces

V. Tverdomed¹, O. Aharkov², V. Boiko³, L. Kushmar⁴

¹State University of Infrastructure and Technology, Kyrylivska Str., 9/3, Kiev, Ukraine, 04080
E-mail: tverdomed@gsuite.duit.edu.ua
²State University of Infrastructure and Technology, Kyrylivska Str., 9/3, Kiev, Ukraine, 04080
E-mail: agarkov_ov@gsuite.duit.edu.ua
³State University of Infrastructure and Technology, Kyrylivska Str., 9/3, Kiev, Ukraine, 04080
E-mail: boyko_vd@gsuite.duit.edu.ua
⁴Kyiv National University of Trade and Economics, Kioto Str., 19, Kiev, Ukraine, 02156
E-mail: l.kushmar@knute.edu.ua

Abstract

The study of the guiding of the vehicle in curves is one of the complex problems of interaction between the track and the rolling stock. These difficulties are due to a large number of factors that affect the nature of the vehicle guiding in curves leading to the necessity to solve a system of equations with a large number of unknowns. The difficult task is to determine the real scheme of the vehicle guiding in curves and, depending on this position, of all the wheels in the curve at different modes of movement; it is unfathomable to consider various structures of the rolling stock, including articulated and non-articulated trolleys; dependence of forces and friction moments on the position of the rotation centre of the trolley; change of sliding friction coefficients in contact of the wheel and the rail at various schemes of the vehicle guiding in curves.

KEY WORDS: curve of the track, trolley, coefficient of sliding friction, horizontal outstanding forces

1. Introduction

The first theoretical studies on the guiding of the vehicle in curves were conducted by Russian scientists during the calculations of the track for the rolling stock strength. In particular, prof. S. N. Smirnov, prof. A. A. Kholodetskyi and prof. K. Yu. Tsehlynskyi have formed basic positions of the method in the guiding of the vehicle in curves, which allowed to find the forces of transverse pressure of wheels on the rails [1]. The rule confirmation in finding the rotation centre of the rolling stock firstly was formed by prof. S. N. Smirnov. According to it, the rotation centre of the rolling stock is on its longitudinal axis at the point of intersection with the perpendicular, drawn from the centre of the curve. Widely used in the engineering practice is the method of calculating the guiding of the vehicle in curves, based on the selection of the necessary installations by gradual approximation.

The generalized analytical method developed by Ph.D., prof. O. P. Yershkov [2] allows us to doing the most complete and accurate assessment of the horizontal transverse forces in the curved sections. This method has been developed on the basis of the results of the theoretical and experimental researches of interaction different types of rolling stock in the track. This method allows us to assessing the magnitude and nature of changes in the horizontal transverse forces in the curved sections of the track due to moving the most diverse and structurally complex types of rolling stock. With its help the trains speed is set, the transverse stability of the track is checked, the stresses arising in the rail base, the pressing of the rail top and the pressure forces of the rail on the intermediate rail securing are determined [3].

Moving along the curve track trolleys can occupy different positions in the track. The chord free position on an internal rail can be at low speeds of movement and excessive increase of an external rail curve or the movement of the back trolley articulated with the first due to the movement. Jamming positions can be at insufficient width of the track and the big length of a rigid trolley base. Skew free position is the most common for the rolling stock and normal operating conditions. Free position without the direction of the axle of the trolley is typical only for the rolling with articulated trolleys (for the second due to the movement). Chord free position on the external rail of the curve occurs during the movement of the rolling stock at high speed along the curve with an insufficient elevation of the external rail [5-7].

It is seen the trolley position in the curve depends on the forces applied to it, i.e. on the arrangement of the curve, its radius and speed [8].

The design features of the rolling stock, especially the connecting system of the body with the trolley, also significantly affect the nature of the vehicle guiding into the curved section of the track [9]. Such features include:

- the body placement on trolleys that can rotate while driving. Vertical loads from the body are transmitted to the trolleys centrally through the vertical axis (in freight cars) or through the side supports (slides) in this case only the longitudinal forces (thrusts, brakes) are transmitted to the vertical axis. In freight cars with a large body roll, it rests on one of the slides of the trolley. In the absence of roll, the gap between the body and the slider will be 2-4 mm. Eight-axle cars are placed on four two-axle trolleys connected in pairs by beams with the corresponding pivot connections;
there are damping and rotating devices between trolleys and the body. Damping devices promote damping of lateral wabbling (swaying) of trolleys on straight lines, but increase transverse forces in curves. Friction forces in the pivots and slides create damping moments of friction, which prevent the free rotation of the trolley in the curve. Rotating devices are designed to return the deflected parts of the rolling stock to their original position, in addition, they act as buffer rods, reduce the dynamic forces of interaction between the body and the trolley. Rotating devices are simultaneously damping. The functions of buffer rod rotating devices to some extent perform buffer spring (cylindrical springs). Special rotating and damping devices being between the body and the trolleys, elastic pendulum supports, pivots with possible movement across the frame of the trolley for the rolling stock are shown in Fig. 1. The calculation schemes correspond to the following rolling stock: the four-axle freight car on the trolleys TsNII-KhZ-0 – Fig. 1, a; the four-axle passenger car on trolleys KVZ-TsNII – Fig. 1, b; the four-axle passenger car on trolleys 68-7012 – Fig. 1, c; the locomotive VL-80, CS-4 – Fig. 1, d; the locomotive CS-8 (CS-7) – Fig. 1, e; the locomotive CS-2 – Fig. 1, f; the locomotive DS 3 – Fig. 1, g.

there is the rolling stock with articulated and non-articulated trolleys (trolleys of the locomotive CS-4). Articulation reduces the trolley wabbling on straight lines and reduces transverse forces; the guide axes (outer in the trolleys) made with elastic supports in the axle boxes or the axes in the place with the axle boxes have transverse elastic connections with the trolley frame (axle boxes with cylindrical elastic guides or with elastic leashes) [10]. Running on the rail, the wheel, passing through the horizontal irregularities of the track, forms a shock-dynamic interaction with this rail. In the presence of adjustable stops, maintaining the interaction elasticity, the resulting forces are transmitted to the frame in a reduced form;

wheel pairs have free longitudinal runs, i.e. the ability to move along the axes in one direction or another [11].

Fig. 1 Schemes of interaction between the body and trolleys: a – span bolster with rigid lateral supports; b – span bolster with cylindrical springs; c – span bolster truck with cylindrical springs; d – span bolster with elastic supports; e – span bolster with side slides; f – span bolster without side slides; g – bolster hanger; 1 – lateral rigid supports (rolling or sliding); 2 – rigid pivot connection (for rigid transmission of longitudinal and transverse forces); 3 – bolster hanger; 4 – elastic pivot connection; 5 – lateral elastic supports with slides; 6 – central pendulum support; 7 – set of springs; 8 – intermediate bolster.

2. Methods and Course of the Study

The graph-passports made by professor O. P. Yershkov in the 60-70 s of last century for the types of rolling stock being used in those years.

At present, some additions and clarifications have been made to the technique of prof. O. P. Yershkov, including the variable value of the friction coefficient in different schemes of the vehicle guiding in curves [12]. In addition, there is a need to determine the transverse forces in the rolling stock of new types.

The analytical method of O. P. Yershkov is the basis of the method in the calculation of transverse horizontal forces in this research. The accepted technique differs from the method of prof. O. P. Yershkov: calculating the transverse horizontal forces for new and old rolling stock, the value of the friction coefficient is not equal to a constant value \( \mu \neq \text{const} \), but it is determined depending on the relative slip of wheels on the rail \( u/v \) [13]. The relative slip differs under different conditions of the vehicle guiding in curves and depends on the radius of the curve and the angle of the wheels on the rail \( (R \neq \text{const}, \alpha \neq \text{const}) \) [14]. \( R \) – is the radius of the curve; \( \alpha \) – the angle of the wheel on the rail, which is determined by the ratio \( x/R \); \( x \) – the distance from the guide of the first axis to the centre of the trolley rotation.

Professor O. P. Yershkov has made approximate formulas (at a constant coefficient of friction), which are in the formula 1, to determine the transverse forces acting on the track from the wheels of the rolling stock:

\[
Y = Y_0 + b \cdot a_{\text{on}},
\]

\( Y_0 \) – magnitude of the transverse force (guide, lateral, frame) when \( a_{\text{on}} = 0 \); \( b \) – angle of the graphic line \( Y = f(a_{\text{on}}) \).
The analytical model of the vehicle guiding in curves is shown in Fig. 2.

![Diagram of vehicle guiding in curves](image)

Fig. 2. The analytical model of the vehicle guiding in curves with articulated trolley. $Y_i$ guiding forces; $H_i$ transverse components of friction forces; $l$ – distances between axles of wheel pairs in the trolley; $f_i$ – distances of wheel flange points from the outer rail; $L_b$ – length of the rigid base of the trolley; $m_i$ – acting moments between the body and the trolley; $S_i$ – acting forces between the body and the trolley; $f_{ci}$ – the size of the arrows between the rail and the frame of the trolley at the joint.

The formula of the equilibrium of the forces in the transverse horizontal plane during the movement of the rolling stock along the curve according to the method of Ph.D. prof. O. P. Yershkov and the analytical model of the vehicle guiding in curves (Fig. 2):

$$
F_{w1} = f(x_1, x_2, K, f_1, Y_1); \\
F_{w2} = f(x_1, x_2, K, f_2, Y_2).
$$

(2)

In the absence of articulated trolleys, the system of Eq. (2) has two unknowns $x_1, x_2$, or $Y_3, Y_6$. For the rolling stock with articulated trolleys, the order of calculation must ensure in the position of the rolling stock quickly finding the value of the internal force $K$ at the joint or moving the ends of the frame at the joint $z_c$. To do this, a system of necessary functions is:

$$
F_{w1} = f(x_1, x_2, K, f_4, Y_4); \\
F_{w2} = f(x_1, x_2, K, f_3, Y_3); \\
F_{w3} = f(x_1, x_2, K, Y_4, Y_6); \\
K = f(x_1, x_2, f_4); \\
f_4 = f(x_1, x_2, f_1); \\
f_3 = f(x_1, f_3); \\
f_6 = f(x_2, f_4).
$$

(3)

Fig. 3 is the example of the graph-passport for the locomotive VL-80. The analysis of the graph-passport shows that graphs of transverse forces dependence on unresolved transverse accelerations are a straight line or slightly curved convexity curve upwards in the direction of increasing transverse forces for the rolling stock with non-articulated trolleys, (Fig. 3). The calculations confirm the validity of the dependences (1).

For the rolling stock with articulated trolleys this dependence remains valid within one stage of the vehicle guiding in curves. Therefore, to determine the effective transverse force accurately is necessary to use the graph-passports given in.

The calculations in the article have confirmed the method, which was proposed by O. P. Yershkov [2], of calculating the vehicle guiding in curves for the rolling stock with a complex system of connection between the body and trolleys in general.

On the basis of the accepted technique [2] there have been carried out verification calculations for the graph-passports of the rolling stock which is typical for the domestic railways and is operated for a long time: the four-axle passenger car on trolleys KVZ-TsNII, the four-axle passenger car on trolleys 68-7012, the locomotive VL-80, CS-4, CS-2, TEP 60.
Formulas for determining the transverse forces in dependence on the outstanding transverse acceleration

<table>
<thead>
<tr>
<th>Rolling stock</th>
<th>Guiding force $Y_1$, kN</th>
<th>Lateral force $Y_2$, kN</th>
<th>Frame force $Y_3$, kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Trolley TsNII-HZ, $R = 300$ m</td>
<td>83,44 + 13,73 $a_{an}$</td>
<td>59,34 + 13,97 $a_{an}$</td>
<td>35,25 + 14,2 $a_{an}$</td>
</tr>
<tr>
<td>Trolley TsNII-HZ, $R = 600$ m</td>
<td>74,45 + 13,28 $a_{an}$</td>
<td>53,32 + 13,51 $a_{an}$</td>
<td>32,2 + 13,74 $a_{an}$</td>
</tr>
<tr>
<td>Trolley TsNII-HZ, $R = 1000$ m</td>
<td>64,74 + 13,14 $a_{an}$</td>
<td>46,69 + 13,37 $a_{an}$</td>
<td>28,64 + 13,31 $a_{an}$</td>
</tr>
<tr>
<td>Trolley TsNII-HZ, $R = 300$ m</td>
<td>53,85 + 20,45 $a_{an}$</td>
<td>37,16 + 18,69 $a_{an}$</td>
<td>20,54 + 20,91 $a_{an}$</td>
</tr>
<tr>
<td>Trolley KVZ-TsNII, $R = 600$ m</td>
<td>47,86 + 20,77 $a_{an}$</td>
<td>32,05 + 17,01 $a_{an}$</td>
<td>18,65 + 20,23 $a_{an}$</td>
</tr>
<tr>
<td>Trolley KVZ-TsNII, $R = 1000$ m</td>
<td>41,89 + 20,53 $a_{an}$</td>
<td>29,41 + 21,05 $a_{an}$</td>
<td>16,92 + 21,39 $a_{an}$</td>
</tr>
<tr>
<td>Trolley 68-7013, $R = 300$ m</td>
<td>44,33 + 27,77 $a_{an}$</td>
<td>25,25 + 23,98 $a_{an}$</td>
<td>11,17 + 28,24 $a_{an}$</td>
</tr>
<tr>
<td>Trolley 68-7013, $R = 600$ m</td>
<td>39,31 + 19,35 $a_{an}$</td>
<td>27,1 + 19,49 $a_{an}$</td>
<td>10,88 + 19,64 $a_{an}$</td>
</tr>
<tr>
<td>Trolley 68-7013, $R = 1000$ m</td>
<td>35,03 + 16,52 $a_{an}$</td>
<td>24,74 + 16,65 $a_{an}$</td>
<td>9,46 + 16,77 $a_{an}$</td>
</tr>
<tr>
<td>VL 80 with non-articulated trolleys, $R = 300$ m</td>
<td>79,87 + 25,43 $a_{an}$</td>
<td>52,77 + 25,6 $a_{an}$</td>
<td>25,67 + 25,78 $a_{an}$</td>
</tr>
<tr>
<td>VL 80 with non-articulated trolleys, $R = 600$ m</td>
<td>71,17 + 25,27 $a_{an}$</td>
<td>47,42 + 25,45 $a_{an}$</td>
<td>23,68 + 25,62 $a_{an}$</td>
</tr>
<tr>
<td>VL 80 with non-articulated trolleys, $R = 1000$ m</td>
<td>64,05 + 25,05 $a_{an}$</td>
<td>42,64 + 25,32 $a_{an}$</td>
<td>21,24 + 25,42 $a_{an}$</td>
</tr>
<tr>
<td>VL 80 with articulated trolleys, $R = 300$ m</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
</tr>
<tr>
<td>VL 80 with articulated trolleys, $R = 600$ m</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
</tr>
<tr>
<td>VL 80 with articulated trolleys, $R = 1000$ m</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
</tr>
<tr>
<td>CS-2 with non-articulated trolleys, $R = 300$ m</td>
<td>85,37 + 29,4 $a_{an}$</td>
<td>60,31 + 29,46 $a_{an}$</td>
<td>35,25 + 29,51 $a_{an}$</td>
</tr>
<tr>
<td>CS-2 with non-articulated trolleys, $R = 600$ m</td>
<td>78,18 + 25,76 $a_{an}$</td>
<td>56,22 + 25,81 $a_{an}$</td>
<td>34,27 + 25,85 $a_{an}$</td>
</tr>
<tr>
<td>CS-2 with non-articulated trolleys, $R = 1000$ m</td>
<td>54,93 + 41,08 $a_{an}$</td>
<td>36,61 + 41,16 $a_{an}$</td>
<td>18,29 + 41,24 $a_{an}$</td>
</tr>
<tr>
<td>CS-4 with non-articulated trolleys, $R = 300$ m</td>
<td>65,93 + 36,63 $a_{an}$</td>
<td>40,87 + 35,69 $a_{an}$</td>
<td>15,81 + 36,74 $a_{an}$</td>
</tr>
<tr>
<td>CS-4 with non-articulated trolleys, $R = 600$ m</td>
<td>63,43 + 31,1 $a_{an}$</td>
<td>41,45 + 31,18 $a_{an}$</td>
<td>19,47 + 31,26 $a_{an}$</td>
</tr>
<tr>
<td>CS-4 with non-articulated trolleys, $R = 1000$ m</td>
<td>55,87 + 24,54 $a_{an}$</td>
<td>37,1 + 34,59 $a_{an}$</td>
<td>18,54 + 34,2 $a_{an}$</td>
</tr>
<tr>
<td>CS-8, CS-7; $R = 300$ m</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
</tr>
<tr>
<td>CS-8, CS-7; $R = 600$ m</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
</tr>
<tr>
<td>CS-8, CS-7; $R = 1000$ m</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
<td>According to the graph-passport</td>
</tr>
<tr>
<td>DS 3; $R = 300$ m</td>
<td>74,12 + 25,26 $a_{an}$</td>
<td>43,25 + 25,49 $a_{an}$</td>
<td>22,38 + 25,72 $a_{an}$</td>
</tr>
<tr>
<td>DS 3; $R = 600$ m</td>
<td>65,28 + 25,06 $a_{an}$</td>
<td>42,61 + 25,3 $a_{an}$</td>
<td>19,94 + 25,53 $a_{an}$</td>
</tr>
<tr>
<td>DS 3; $R = 1000$ m</td>
<td>55,85 + 24,9 $a_{an}$</td>
<td>36,49 + 25,12 $a_{an}$</td>
<td>17,13 + 25,43 $a_{an}$</td>
</tr>
</tbody>
</table>
The new method in the article was used for the calculations and the graph-passports for the new rolling stock were made: for the passenger car on trolleys, model 68-7012 and the locomotives of modern production DS-3 and CS 8. Calculations have been made for curves of radii 300 m, 600 m, 1000 m. Table 1 shows the results of these calculations [15].

The dependences of the transverse forces can be described by the formula:

\[ Y = f(P_m, R, \alpha_{se}, m, \mu) \]  \hspace{1cm} (6)

3. Conclusions

The calculations in the research expand the main items of the method of the vehicle guiding in curves and determine the transverse forces. This method allows us to take into account the impact on the transverse forces of the structure parameters and characteristics, the condition of the rolling stock and the track without taking into consideration the inertia forces arising due to oscillations of sprung and unsprung parts of the rolling stock.

1. The main features of the generalized method of the vehicle guiding in curves include:
   - wide functions application of specific characteristics of the vehicle guiding that allows to avoid selection of arguments;
   - maximum use of opportunities to obtain analytical solutions in the final form for a large number of the rolling stock;
   - the introduction in the calculation of the transverse force on the outstanding acceleration as the main dependence allowed to use the linearity to build graph-passports widely.

2. The developed method of the vehicle guiding in curves allows to determine the impact on the level of transverse forces of the damping moment, articulation of trolleys (influence of pre-pressure and stiffness of springs at the joint), rotating devices in the body supports with different stiffness characteristics and the axes difference in a wide range of speeds, radii of curves and increase.

3. Graph-passports allow obtaining transverse forces from the speed of movement, the radius of the curve and the increase of the outer rail.

4. The introduction of damping moments increases the pole distances of the first trolley and reduces it in the second trolley. At damping moments, the first trolleys run in a track with the big skew. The presence of a damping moment leads to an increase in transverse forces.

5. Analysing the obtained graph-passports for the locomotive VL-80 with articulated and non-articulated trolleys, it is seen that articulation at any speed reduces the amount of transverse forces acting on the outer rail. In a curve with a radius of 1000 m, the percentage reduction in the guiding force of the first trolley is within 20%. In the presence of articulation of trolley, the pole distances x1 and x2, the rotation angle of the last trolley decreases, i.e. articulated trolleys run in a track with less skew relative to the track. Taking into consideration that the articulation reduces the guide forces and angles of attack, it is expected the lateral fretting reduction of the outer rails in the curves.

6. Calculating the vehicle guiding in curves with taking into account the outstanding centrifugal accelerations in the most practical cases, it is sufficient to determine the force interaction at the rigid track.

6. The calculations of the transverse interaction of the track and the rolling stock indicate the dependence: between the transverse forces and the static load on the wheel of the rolling stock, which can be seen from the graph; between the transverse forces and the geometry of the track, which can be seen from the graph-passports. As the radius of the curve increases, the transverse forces decrease; between the transverse forces and the outstanding centrifugal acceleration, which depends on the speed and magnitude of the increase in the outer rail, there is a formula. Analyzing the graph-passport of the locomotive VL-80 without articulation of trolleys for a curve with a radius of 300 m it is seen that with the increase in the value of centrifugal acceleration the value of the transverse force increases; between the transverse forces and the magnitude of the damping moment that occurs between the body and the trolleys; between the transverse forces and the coefficient of sliding friction between the wheel and the rail.

References


Author's Index

A
Adamová V., 696
Aharkov O., 1037
Akušis I., 777
Andrulytė A., 829
Anne O., 640
Astaykin D., 662
Ažaltovič V., 938

B
Babyak M., 646
Bagocius D., 640
Ballay M., 702
Barta D., 584
Batarhienė N., 594
Benda M., 810
Beneda K., 731
Bezovska M., 568
Biéliková A., 865
Blaheova M., 889
Bogdevičius M., 1032
Bogusz D., 946
Boiko V., 1037
Bondarenko A., 662
Boroš M., 884
Breznicka A., 676, 716
Budek S., 824
Bulgakov O., 662
Bureika G., 743, 855
Burmaka I., 753
Burmaka O., 773

C
Caban J., 584
Chandrasekaran V., 814
Chlumecký J., 1000
Ciszewski T., 666
Č
Čerňan J., 942, 985

D
Darguzis A., 1010
Dávid A., 900
Dementjev A., 996
Dižo J., 878
Djackov V., 920
Dobroselskyi M., 599
Dobržinskitė N., 894
Dotsenko S., 671
Droppa P., 979
Dvořák P., 781

E
Endriulaitienė A., 721

F
Faidusiene R., 640
Fedaravičiūtė A., 820, 845
Filina-Dawidowicz L., 579
Froněk J., 1000

G
Gajanova L., 737
Galieriková A., 900
Gašpariková Z., 1006
Gavrilovs P., 906
Gill A., 804, 850
Gladkyh I., 634, 860
Golikov A., 662, 860
Górnikiewicz M., 560
Guseinović E., 920

H
Haichenia O., 707
Hakalová J., 865
Horníček T., 1000
Hoštáková D., 599
Hrabovenko O., 671
Hulek D., 618

I
Indriksons R., 974
Ivaninoka I., 548

Y
Yanchetskyy O., 753

J
Jangl Š., 884
Jankunas V., 920
Janoskova K., 969
Jarašūnienė A., 594
Jasas G., 952
Javorčík T., 628
Jelinek J., 676, 716
Juodvalkis D., 777

K
Kadziński A., 804
Kalnina R., 548
Kampová K., 916
Kandera B., 589, 938
Katinienė A., 855
Kavas L., 731
Keršys A., 845
Keršys R., 646
Khussein Y., 753
Kicova E., 1017
Kobaszynińska-Twardowska A., 762
Kolegaiev M., 757
Kolegayev I., 757
Kolla E., 696
Korecki Z., 925
Kornaszewski M., 683
Kotkova B., 872
Kováčik L., 960
Kozicki B., 560, 824
Kozuba J., 925
Kral P., 969
Kriveovas A., 894
Kryšková Š., 865
Krobot Z., 676, 716
Kruntorád J., 628
Kubáňová J., 767
Kubasáková I., 767
Kudláč Š., 689
Kulakov M., 753, 785, 860
Kushmar L., 1037

L

Lendraitis M., 797
Litvaitis R., 1028
Lukasiewicz J., 762
Łukasik Z., 666
Łukáš P., 979
Łukoševičius V., 797, 814
Lusiak T., 589
Lusková M., 711

M

Madleňák R., 599
Madleňáková L., 833
Majercak J., 689, 956
Majercak P., 956
Majerova J., 737
Makaras R., 797, 1028
Mákká K., 916
Maňas P., 781
Marcheva M., 979
Marko M., 979
Markšaitytė R., 721
Martinkutė G., 605
Medvedieva I., 785
Mendel R., 726
Morneva M. 554

N

Nadanyiova M., 737
Neduzha L., 568
Neduzha L., 646
Nesterenko V., 671
Niuronis S., 1022
Novák A., 589
Novák A., 960
Novák M., 618
Novák Sedláčková A., 589
Nowakowski W., 666

O

Oleynik J., 634, 785
Omelchenko T., 773

P

Paliakienė I., 605
Palochová M. 865
Parczewski K., 541
Paulauskas V., 579
Pavelčík V., 584
Perun P., 991
Petkevičius K., 845
Petričhenko I., 773
Pilkauskas K., 845
Pniewski R., 683
Ponisciaikova O., 1017
Poparovský V., 964
Popov V., 748
Prievozník P., 702
Pirimachov N., 757
Pšenková Y., 865
Purkart P., 628

R

Raynov A., 634, 785
Řeha D., 618
Rimkienė-Kelpašė L., 640
Rozyte D., 1032

S

Sapronova S., 554
Savkovs K., 652
Sawicka M., 656
Severin V., 707
Shepel V., 634
Shevchenko A., 748
Shvets I., 671
Sikirin V., 707
Sisák T., 985
Sivykh D., 840
Skudnov V., 748
Skvireckas R., 568
Slavinskiene J., 721
Sližys E., 820
Smoczyński P., 804, 850
Sobotka J., 810
Sokołowska L., 622
Sosedová J., 900
Stajniak M., 824
Steisūnas S., 878
Stodola J., 676, 716
Stodola P., 676, 716
Stonys G., 1022
Straško A., 850
Sumiša M., 612, 656
Surviša A., 820, 845
Sventeková E., 702, 1006

Š

Šafranko J., 925
Šaulys P., 1022
Šeibokaitė L., 721
Škultėtė F., 942, 985
Škareková I., 938
Šprunčová K., 767
Štoller J., 781

T

Tchórzewski K., 656
Tkachenko V., 554
Tomaszewski J., 824
Trynov O., 840
Turská S., 833
Tverdomed V., 1037
Týfa L., 628

U

Urbaha M., 652

V

Vabolys M., 1022
Vaičiūnas G., 790, 878
Vaičiūtė K., 855
Valba D., 743
Varga B., 731
Vasiljevs A., 748
Velčhko G., 573, 910
Venkatesh N. H., 1010
Vymėtal D., 1000
Volkov O., 773
Vorokhbin I., 707, 860

W

Wnąk H., 541

Z

Zapnickas T., 920
Zaripov R., 906
Zelenko Yu., 568
Zharkova V., 618
Zmeškal E., 689
Zub E., 554
Zvaková Z., 726

Ž

Žukauskaitė A., 605
Žukauskaitė J., 605
## Contents

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>540</td>
</tr>
<tr>
<td>K. Parczewski, H. Wnęck. Comparison of Overcoming Inequalities of the Road by a Vehicle with a Conventional Drive System and Electric Motors Placed in the Wheels</td>
<td>541</td>
</tr>
<tr>
<td>R. Kalniņa, I. Ivaniniska Treatments of Ships Sewage: A Theoretical Analysis</td>
<td>548</td>
</tr>
<tr>
<td>V. Tkachenko, S. Sapronova, E. Zub, M. Morneva. Closed Power Loops in the Guidance of Vehicles by Railway Track System</td>
<td>554</td>
</tr>
<tr>
<td>B. Kozicki, M. Górnikiewicz. The Forecasting of Government Revenues in Poland in the Aspect of Security</td>
<td>560</td>
</tr>
<tr>
<td>Yu. Zelenko, M. Bezovska, R. Skvireckas, L. Neduzha. The Impact of Motor Oils Quality on Improving the Reliability in Operation of Traction Rolling Stock</td>
<td>568</td>
</tr>
<tr>
<td>G. Velichko. Quality Analysis and Evaluation Technique of Railway Track + Vehicle System Performance at Railway Transition Sections with Various Shape Curves</td>
<td>573</td>
</tr>
<tr>
<td>L. Filina-Dawidowicz, V. Paulauskas. Obstacles and Benefits of Real Time Information Exchange Between the Ferry and Shipping Users</td>
<td>579</td>
</tr>
<tr>
<td>D. Barta, V. Pavelčík, J. Caban. Rapid Prototyping Used in the Automotive Rubber Parts Production</td>
<td>584</td>
</tr>
<tr>
<td>A. Novák, A. Novák Sedláčková, B. Kandera, T. Lusiak. Flight Inspection with Unmanned Aircraft</td>
<td>589</td>
</tr>
<tr>
<td>R. Madleňák, D. Hoštákova, M. Dobroselskyi. The Modelling of Post Office Time Availability by Isochrones</td>
<td>599</td>
</tr>
<tr>
<td>G. Martinkutė, A. Žuksauskaitė, J. Žuksauskaitė, I. Paliakienė. The Impact of Cruise Shipping Pollution on Greenhouse Effect in the Port of Klaipeda</td>
<td>605</td>
</tr>
<tr>
<td>M. Sumila. Viewpoint on Cybersecurity in FRMCS</td>
<td>612</td>
</tr>
<tr>
<td>D. Hůlek, D. Řeha, V. Zharkova, M. Novák. The Proposal of the Examination Credits Granting Procedure According to the PART 66</td>
<td>618</td>
</tr>
<tr>
<td>L. Sokolowska. Standardization of Selected Interfaces of Railway Traffic Control Equipment and Systems – Aspects of Cyber Security and Transmission Safety</td>
<td>622</td>
</tr>
<tr>
<td>P. Purkart, J. Kruntorád, T. Javofík, L. Týfa. The Choice Restriction Model of the Mean of Transport due to the Route Capacity</td>
<td>628</td>
</tr>
<tr>
<td>D. Bagocius, L. Rimkiene-Kelpsaite, R. Faidusiene, O. Anne. Waterborne Transport Contribution to the Lithuanian Marine and Near-Shore Pollution</td>
<td>640</td>
</tr>
<tr>
<td>M. Babyak, R. Keršys, L. Neduzha. Improving the Dependability Evaluation Technique of a Transport Vehicle</td>
<td>646</td>
</tr>
<tr>
<td>M. Sumila, K. Tchorzewski, M. Sawicka. Assessment Requirements TSI CCS for the Trackside Subsystem in the Field of GSM-R Coverage</td>
<td>656</td>
</tr>
</tbody>
</table>
D. Astaykin, A. Golikov, A. Bondarenko, O. Bulgakov. The Effectiveness of Ship's Position Using the Laws of Distribution of Errors in Navigation Measurements

T. Ciszewski, W. Nowakowski, Z. Lukasik. Implementation of Railway Infrastructure Visualization Using Data Collected in railML

I. Shvets, O. Hrabovenko, S. Dotsenko, V. Nesterenko. Results of the Experimental Research of the Medium Speed Diesel Engine Work on Soybean Oil


Š. Kudláč, J. Majerčák, E. Zmeškal. The Methodology for Evaluating Constraints in Logistics Chains while Utilising Intermodal Transport

E. Kolla, V. Adamová. Reconstruction of Emergency Vehicle Traffic Accident Using On-Board Camera Recording and Point Cloud Obtained by the Agisoft Metashape Program

E. Sventeková, M. Ballay, P. Prievozník. System Approach to Assessing the Criticality of Key Elements in Road Transport


M. Lusková. Land Transport Vulnerability to Power Failure

J. Stodola, Z. Krobot, A. Breznicka, J. Jelinek, P. Stodola. Degradation of Equipment and Material in Long-Term Storage


Z. Zvaková, R. Mendel. Aspects of the Use of Motor Vehicles in the Intervention Activities of Private Security Services in a Selected Region

B. Varga, L. Kavas, K. Beneda. What is the Way Forward? Or What Kind of Challenges the Engine Manufacturers of International Aviation Industry Have to Face

J. Majerova, L. Gajanova, M. Nadanyiova. Loyal Locally vs. Loyal Globally: Comparative Study of Brand Value Sources in Contemporary Automotive Market

D. Valba, G. Bureika. Study of Braking Dynamics of Long and Heavy Trains on Track Downlines with a Curve

V. Popov, V. Skudnov, A. Shevchenko, A. Vasiljevs. Application of Software Complexes for Monitoring of Cellular Networks of Mobile Communication KPI on Railway Transport

I. Burmaka, M. Kulakov, Y. Khussein, O. Yanchetskyy. Methods of Ships' External Steering in Condition of Close Quarters Situation

M. Kolegaiev, N. Primachov, I. Kolegayev. Systematic Efficiency of Global Merchant Shipping Power Safety

A. Kobaszyńska-Twardowska, J. Lukasiewicz. Identification of Hazards Sources for the Use of Unmanned Aerial Vehicles (UAV) in Urban Airspace

J. Kubáňová, I. Kubasáková, K. Špruncová. The Impact of the Telematics Systems Using in the Road Freight Transport Business
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>O. Burmaka, O. Volkov, T. Omelchenko, I. Petrichenko. Application of Infeasible Region Parameters for Prevention Collisions by Ships</td>
<td>773</td>
</tr>
<tr>
<td>I. Akūnis, D. Juodvalkis. Research of LPG use in Diesel Engines</td>
<td>777</td>
</tr>
<tr>
<td>G. Vaičiūnas. Assessment of Railway Development in Baltic Sea Region</td>
<td>790</td>
</tr>
<tr>
<td>M. Lendraitis, V. Lukoševičius, R. Makaras. Aerodynamic Optimization of the Wing Trailing Edge Flap</td>
<td>797</td>
</tr>
<tr>
<td>P. Smoczyński, A. Gill, A. Kadziński. Safety Recommendations as a Method of Strengthening Resilience of the Railway System</td>
<td>804</td>
</tr>
<tr>
<td>J. Sobotka, M. Benda. C-IED Polygon – New trends in Military Training</td>
<td>810</td>
</tr>
<tr>
<td>V. Chandrasekaran, V. Lukoševičius. Study of Vehicle ESP System and Analysis of Vehicle Dynamics</td>
<td>814</td>
</tr>
<tr>
<td>A. Fedaravičius, E. Sliţys, A. Survila. Experimental Research of Solid Propellant Rocket Motor Internal Ballistics Characteristics</td>
<td>820</td>
</tr>
<tr>
<td>A. Andrułyté. Research of Tugboats Pollution in Klaipėda Port</td>
<td>829</td>
</tr>
<tr>
<td>L. Madleňáková, S. Turská. Modeling Postal Operations in Crisis Situation</td>
<td>833</td>
</tr>
<tr>
<td>O. Trynov, D. Sivykh. The Local Cooling System for the Valve Unit of Automotive Diesel Engines</td>
<td>840</td>
</tr>
<tr>
<td>A. Fedaravičius, K. Petkevičius, K. Pilkauskas, A. Keršys, A. Survila. Research of the Rocket Target Airframe Strength Characteristics</td>
<td>845</td>
</tr>
<tr>
<td>A. Straško, P. Smoczyński, A. Gill. Audit of Passenger Information Signs on Poznań Główny Railway Station</td>
<td>850</td>
</tr>
<tr>
<td>K. Vaičiūtė, A. Katinienė, G. Bureika. Assessment of the Impact of Road Transport Enterprise Technological Development on Arranging of Freight Transportation by Rail</td>
<td>855</td>
</tr>
<tr>
<td>I. Gladkykh, A. Golikov, I. Vorokhobin, M. Kulakov. Development Prospects of the Ukrainian Section of the Shipping Route E-40</td>
<td>860</td>
</tr>
<tr>
<td>J. Hakalová, A. Bieliková, Š. Kryšková, Y. Pšenková, M. Palochová. The Use of Passenger Cars in Business in the Czech Republic in the Context of Developments and Trends in Financing and Accounting and Tax Aspects</td>
<td>865</td>
</tr>
<tr>
<td>B. Kotkova. Use of Software for Licence Plate Recognition in Road Traffic</td>
<td>872</td>
</tr>
<tr>
<td>G. Vaičiūnas, S. Steišiūnas, J. Džo. The Nadal Criterion Study in a Passenger car with Independently Rotating Wheels</td>
<td>878</td>
</tr>
<tr>
<td>M. Boroš, Š. Jangl. Testing of the Reliability of Vehicles Monitoring in a Selected Region</td>
<td>884</td>
</tr>
<tr>
<td>M. Blahova. Critical Road Transport Infrastructure</td>
<td>889</td>
</tr>
<tr>
<td>A. Krivcovas, N. Dobrzhinskij. Study of Problems Faced when Establishing Military Field Camps</td>
<td>894</td>
</tr>
<tr>
<td>R. Zaripov, P. Gavrilovs. Assessment of the Economic Efficiency of Modernization of Railway Wagons</td>
<td>906</td>
</tr>
<tr>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>G. Velichko. Shape Harmonization of the Railway Track Transition Section &amp; the Kinematics of Vehicle Body Design Point</td>
<td>910</td>
</tr>
<tr>
<td>K. Mäkká, K. Kampová. Safety Analysis of Accident During Dangerous Substances Transport</td>
<td>916</td>
</tr>
<tr>
<td>V. Djackov, E. Guseinoiene, V. Jankunas, T. Zapnickas. Investigation of the Efficiency of Small Electric Ship Propulsion and Battery Energy Control Systems</td>
<td>920</td>
</tr>
<tr>
<td>Z. Korecki, J. Kozuba, J. Šafranko. Dynamic Assessment of Critical Infrastructure Resilience in Airport Landside</td>
<td>925</td>
</tr>
<tr>
<td>V. Ažaltovič, I. Škvareková, B. Kandera. Analysis of Long-Term and Maintenance Parameters and Their Impact on Degradation of UAV Accumulators</td>
<td>938</td>
</tr>
<tr>
<td>J. Čerňan, F. Škultéty. Design of the Air Velocity Measuring Inlet Channel for the Small Jet Engine</td>
<td>942</td>
</tr>
<tr>
<td>D. Bogusz. The Impact of Training Organization on the Effectiveness of Training in Spatial Disorientation</td>
<td>946</td>
</tr>
<tr>
<td>G. Jasas. Study of Panamax Type Ships Impact Arriving for Repairs on Pollution in the Port of Klaipeda</td>
<td>952</td>
</tr>
<tr>
<td>L. Kováčik, A. Novák. The Role of Aerial Application in Slovakia in the 21st Century</td>
<td>960</td>
</tr>
<tr>
<td>V. Popardovský. Dynamic Analysis of Unmanned Ground Tracked Vehicle</td>
<td>964</td>
</tr>
<tr>
<td>P. Kral, K. Janoskova. Forecast of Traffic Accidents in Road Transport in the Slovak Republic</td>
<td>969</td>
</tr>
<tr>
<td>R. Indriksons. The Effect of the Propeller Shaft Torsional Vibrations on The Accuracy of the Power Measurement</td>
<td>974</td>
</tr>
<tr>
<td>P. Lukášik, M. Marko, P. Droppa, M. Marchevka. The Long Journeys Impact on Quality Parameters of Engine Oils in IVECO CROSSWAY Buses with CR Diesel Engines</td>
<td>979</td>
</tr>
<tr>
<td>F. Škultéty, J. Čerňan, T. Sisák. VTOL Design for Fixed Wing UAVs</td>
<td>985</td>
</tr>
<tr>
<td>P. Perun. Influence of Powder Mass on Barrel’s Muzzle Vibration</td>
<td>991</td>
</tr>
<tr>
<td>A. Dementjiev. Research of Air Pollution Possibilities of Panamax Containerships Sailing to Klaipeda Container Terminal in the Port of Klaipeda</td>
<td>996</td>
</tr>
<tr>
<td>E. Sventeková, Z. Gašpariková. Basis for Simulating the Permeable Performance of Rail Transport in Crisis Situations</td>
<td>1006</td>
</tr>
<tr>
<td>N. H. Venkatesh, A. Darguzis. Research on Controlled Semi Active Suspensions in Passenger Car</td>
<td>1010</td>
</tr>
<tr>
<td>M. Vabolys, P. Šaulys, S. Niauronis, G. Stonys. Modelling and Experimental Assessment of Dynamic Parameters of Mobile Robot Chassis</td>
<td>1022</td>
</tr>
<tr>
<td>M. Bogdevicius, D. Rozyte. Investigations of Short - Term Maneuvering Behavior of Vehicles Moving on Snowy Roads</td>
<td>1032</td>
</tr>
<tr>
<td>V. Tverdomed, O. Aharkov, V. Boiko, L. Kushmar. Calculation of Transverse Horizontal Forces</td>
<td>1037</td>
</tr>
</tbody>
</table>